Docket No.: 50212-132

REQUEST FORM FOR CONTINUATION APPLICATION UNDER 35 USC 111(a)

Prior Application: **International Application No. PCT/JP00/01660**
    Art Unit: **(Unassigned)**
    Examiner: **(Unassigned)**

Assistant Commissioner for Patents
Washington, DC 20231

Sir:

This is a Request for filing a continuation or continuation-in-part application, entitled OPTICAL

AMPLIFIER AND OPTICAL AMPLIFICATION METHOD, under 35 U.S.C. 111(a) of pending prior International

Application No. PCT/JP00/01660, filed on March 17, 2000, entitled OPTICAL AMPLIFIER AND OPTICAL

AMPLIFICATION METHOD, by the following named inventor(s):

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1. ☒   I hereby verify, to the best of my knowledge, that the enclosed copy of this prior application is a true copy of the above-identified prior application, including the oath or declaration as originally filed.

2. ☐   Preliminary Amendment is enclosed.

2a. ☑ An Information Disclosure Statement and PTO1449 Form are submitted herewith.

3. ☐ Cancel claims .

4. The filing fee is calculated on the basis of the claims existing in the prior application as amended at 3 above:

	NO. OF CLAIMS		EXTRA CLAIMS	RATE	AMOUNT
Total Claims	27	-20	7	$18.00 =	$126.00
Independent Claims	2	-3	0	$78.00 =	$0.00
Basic Application Fee					$690.00
If multiple dependent claims are presented, add $260.00					$0.00
Total Application Fee					$816.00
Subtract ½ if small entity					$0.00
TOTAL APPLICATION FEE DUE					$816.00
AMOUNT TO BE CHARGED TO DEPOSIT ACCOUNT NO. 500417					$816.00

4a. ☐ Enclosed is a Verified Statement to establish small entity status under 37 CFR 1.9 and 37 CFR 1.27.

4b. ☐ A verified Statement to establish small entity status under 37 CFR 1.9 and 37 CFR 1.27 was filed in prior application and such status is still proper and desired.

5. ☒ The Commissioner is hereby authorized to charge fees under 37 CFR 1.16 and 1.17 which may be required, including any extension of time fees including any extension of time fees to maintain the pendency of this application or credit any overpayment to Deposit Account No. 500417.

6. ☐ Amend the specification by inserting before the first line the sentence:

7. ☒ Priority of Patent Application Serial No. 1999-196251, filed on July 9, 1999 in Japan; Patent Application Serial No. 1999-212190, filed on July 27, 1999 in Japan; and International Application No. PCT/JP00/01660 filed March 17, 2000 designating the U.S. is claimed under 35 USC 119, 120 and/or 365.

8. ☐ The prior application is assigned of record to

9. ☐ The power of attorney in the prior application is to:

10. ☒   Also enclosed:

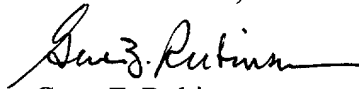Assignment and recordation fee of $40.00

11. ☐   A petition, fee and response has been filed to extend the term in the pending prior application until   .

12. ☒   Address all future communications to: (May only be completed by applicant, or attorney or agent of record)

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Respectfully submitted,

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TITLE OF THE INVENTION

OPTICAL AMPLIFIER AND OPTICAL AMPLIFICATION METHOD

RELATED APPLICATIONS

This is a Continuation-In-Part application of
International Patent Application serial No.
PCT/JP00/01660 filed on March 17, 2000 now pending.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an optical
amplifier and optical amplification method of
amplifying, at once, a multiplexed signal in which a
plurality of signal light components having different
wavelengths belonging to a predetermined wavelength
band are multiplexed.

Related Background Art

The optical amplifier which amplifies signal light
by guiding to a waveguide doped with a fluorescent
material together with optical pumping light of such
fluorescent material is well known. Such an optical
amplifier is provided in a relay station in an optical
transmission system. Especially, an optical amplifier
used in a wavelength-multiplexed transmission system
for transmitting multiplexed signal light in which a
plurality of signal light components having different
wavelengths are multiplexed optically must amplify the
plurality of signal light components at once at an

equal gain, and also amplify the power of each of the plurality of signal light components to a predetermined target value and output the signal light.

For example, reference 1, K. Inoue, et al., "Tunable Gain Equalization Using a Mach-Zehnder Optical Fiber in Multistage Fiber Amplifiers", IEEE Photonics Technology Letters, Vol. 3, No. 8, pp. 718 - 720 (1991) is disclosed a technique of flattening the gain of an optical amplifier by an optical fiber using a Mach-Zehnder interferometer. Reference 2, S. Kinoshita, et al., "Large Capacity WDM Transmission Based on Wideband Erbium-Doped Fiber Amplifiers", OSA TOPS, Vol. 25, pp. 258 - 261 (1998) is disclosed a technique in which an optical attenuator with a variable attenuation factor is inserted between the input-side optical amplification section and the output-side optical amplification section of an optical amplifier so as to maintain constant power of signal light input to the output-side optical amplification section even when the power of signal light input to the input-side optical amplification section varies, thereby maintaining the power of signal light output from the optical amplifier at a predetermined target value and simultaneously maintaining constant gain deviation of the entire optical amplifier.

SUMMARY OF THE INVENTION

In the technique described in reference 1, however, for example, to keep the power of signal light output from the optical amplifier at a predetermined target value when the loss in the input-side transmission line of the optical amplifier varies due to some reason, and the power of signal light input to the optical amplifier varies, the gain of optical amplification of signal light in the optical amplifier must be changed. If the gain is changed, the wavelength dependence of gain varies. This damages the gain flatness of the optical amplifier, and the plurality of signal light components output from the optical amplifier have different powers or so-called deviation.

In the technique described in reference 2, to keep the power of signal light input to the output-side optical amplification section at a predetermined target value by the optical attenuator when the signal light input to the input-side optical amplification section has sufficiently high power, the power must be largely attenuated by the optical attenuator. As a result, the pumping efficiency lowers to degrade the noise factor.

The present invention has been made to solve the above problems, and has as its object to provide an optical amplifier and optical amplification method capable of maintaining the output signal light power

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and gain flatness without degrading the noise factor even when the input signal light power varies.

In order to achieve the above object, according to the present invention, there is provided an optical amplifier for amplifying, at once, multiplexed signal light belonging to a predetermined wavelength band, in which a plurality of signal light components having different wavelengths are multiplexed, characterized by comprising (1) one or a plurality of optical amplification sections each of which has an optical waveguide doped with a fluorescent material and amplifies the multiplexed signal light by optical pumping of the fluorescent material, (2) an optical pumping light source for supplying predetermined optical pumping light to the optical amplification section, (3) an optical filter capable of changing a gradient $dL/d\lambda$ of a loss L (dB) with respect to a wavelength λ (nm) in the predetermined wavelength band, and (4) control means for controlling an optical pumping light output from the optical pumping light source such that light power after amplification has a predetermined target value, and for adjusting a characteristic of the optical filter to adjust a final gain characteristic.

On the other hand, an optical amplification method according to the present invention is characterized by

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,comprising the steps of (1) guiding the multiplexed
signal light to an optical waveguide doped with a
fluorescent material together with predetermined
optical pumping light and optically amplifying the
multiplexed signal light, (2) guiding at least one of
the multiplexed signal light before amplification and
that after amplification to an optical filter capable
of changing a gradient $dL/d\lambda$ of a loss L (dB) with
respect to a wavelength λ (nm) in the predetermined
wavelength band and adjusting the gradient $dL/d\lambda$ of the
optical filter to reduce a wavelength-dependent gain in
the optical amplification, and (3) adjusting an
intensity of the optical pumping light to adjust light
power after amplification to a predetermined target
value.

According to the optical amplifier or optical
amplification method of the present invention, even
when the input signal light power to the optical
amplifier varies, the output signal light power from
the optical amplifier can be maintained at a
predetermined target value. In addition, even when the
gain of the optical amplification section has a
wavelength dependence due to variation in input signal
light power, the gain flatness of the entire optical
amplifier can be maintained by adjusting the gradient
$dL/d\lambda$ of the loss L of the optical filter with respect

.to the wavelength λ.

This optical filter preferably satisfies

L ≈ $a(\lambda - \lambda c) + b$ ·

(where λc (nm) and b (dB) are constants) in the
predetermined wavelength band and changes a (dB/nm) to
adjust the gradient dL/dλ. Such an optical filter can
easily adjust the gradient dL/dλ. When λc is set in the
predetermined wavelength band, the loss L at the
wavelength λc in the predetermined wavelength band
always becomes constant. This enables design with an
emphasis on the noise characteristic at λc.

The optical amplifier may further comprise a gain
equalizer for compensating for a inherent wavelength-
dependent gain of the optical amplification section.
In this case, the gain equalizer equalizes the inherent
wavelength-dependent gain of the optical amplification
section, and the optical filter compensates for
variation in input multiplexed signal light power.
This makes the gain flatness of the entire optical
amplifier more excellent and facilitates
control/adjustment.

Preferably, the optical amplifier further
comprises a wave number monitor for detecting the
number of signal light components contained in the
multiplexed signal light, and the control means adjusts
the target value of light power after amplification in

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accordance with the number of signal light components detected by the wave number monitor. Even when the power of input multiplexed signal light varies due to an increase/decrease in the number of signal light

5   components, the power of each multiplexed signal light component can be maintained constant.

The gradient $dL/d\lambda$ of the optical filter may be adjusted, e.g., 1) on the basis of the detection result from input light power detection means for detecting

10   the light power input to the optical amplification section, 2) on the basis of the detection result from gain detection means for detecting a gain of the optical amplification section, 3) on the basis of power deviation between shortest and longest wavelengths

15   detected by detecting each wavelength and power of signal light components contained in the light output from the optical amplification section, or 4) such that a level difference between ASE light levels detected by ASE light level detection means for detecting an ASE

20   light level of each of wavelengths outside two ends of the predetermined wavelength band of the light output from the optical amplification section. Each wavelength and power of signal light components contained in the light output from the optical

25   amplification section may be detected, and an ASE light level of a wavelength at a shorter wavelength than

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·detected shortest wavelength and at a longer wavelength than detected longest wavelength may be detected and used for adjustment. In case 3) or 4), a wavelength for which the power deviation or ASE light level is to

5   be detected may be determined on the basis of information related to the shortest and longest wavelengths, which are sent together with the multiplexed signal light.

In addition, when a total transmittance in the

10   predetermined wavelength band of the optical filter is adjusted to a maximum value, the loss L is preferably adjusted to be substantially constant independently of the wavelength. This enables to reduce the noise factor especially when the input multiplexed signal

15   light power is small.

Any one of the above arrangements and methods facilitates adjustment of the gradient $dL/d\lambda$ of the optical filter and realizes the object of the present invention.

20   The optical filter in the optical amplifier according to the present invention preferably comprises (1) a main optical path which guides the multiplexed signal light and is divided into first to sixth regions sequentially from an upstream side, (2) a first sub

25   optical path which is arranged close to the first and third regions of the main optical path so that optical

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coupling of propagation light occurs, is spaced apart
from the second region of the main optical path so that
optical coupling of the propagation light does not
occur, and has a region corresponding to the second

5   region of the main optical path, the region having a
length different from that of the main optical path,
(3) a second sub optical path which is arranged close
to the fourth and sixth regions of the main optical
path so that optical coupling of the propagation light

10   occurs, is spaced apart from the fifth region of the
main optical path so that optical coupling of the
propagation light does not occur, and has a region
corresponding to the fifth region of the main optical
path, the region having a length different from that of

15   the main optical path, (4) a first temperature
adjusting device arranged in at least one of the second
region of the main optical path and the region of the
first sub optical path, which corresponds to the second
region of the main optical path, and (5) a second

20   temperature adjusting device arranged in at least one
of the fifth region of the main optical path and the
region of the second sub optical path, which
corresponds to the fifth region of the main optical
path.

25   On the other hand, in the optical amplification
method according to the present invention, preferably,

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·an optical filter comprising (1) a main optical path

which guides the multiplexed signal light and is

divided into first·to sixth regions sequentially from

an upstream side, (2) a first sub optical path which is

5   arranged close to the first and third regions of the

main optical path so that optical coupling of

propagation light occurs, is spaced apart from the

second region of the main optical path so that optical

coupling of the propagation light does not occur, and

10   has a region corresponding to the second region of the

main optical path, the region having a length different

from that of the main optical path, and (3) a second

sub optical path which is arranged close to the fourth

and sixth regions of the main optical path so that

15   optical coupling of the propagation light occurs, is

spaced apart from the fifth region of the main optical

path so that optical coupling of the propagation light

does not occur, and has a region corresponding to the

fifth region of the main optical path, the region

20   having a length different from that of the main optical

path is used, and the gain wavelength dependence

reduction step comprises adjusting at least one of a

temperature in the first sub optical path and a

temperature in a region of the main optical path, which

25   corresponds to the first sub optical path, and at least

one of a temperature in the second sub optical path and

a temperature in a region of the main optical path, which corresponds to the second sub optical path to adjust the gradient $dL/d\lambda$ of the optical filter.

Each of the first and second sub optical paths and the corresponding main optical path form a Mach-Zehnder interference device. In each Mach-Zehnder interference device, when the temperature of at least one of the optical paths is adjusted, the wavelength dependence of loss in each main optical path can be adjusted. Hence, this optical filter is suitable for the optical amplifier and optical amplification method according to the present invention.

The present invention will be more fully understood from the detailed description given hereinbelow and the accompanying drawings, which are given by way of illustration only and are not to be considered as limiting the present invention.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will be apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing the arrangement of an optical amplifier according to the first embodiment of the present invention;

Fig. 2 is an explanatory view of the output-side optical amplification section and optical pumping light source, and Fig. 3 is an explanatory view of the optical filter;

Figs. 4 to 6 are graphs showing loss spectra obtained when a phase value $\Delta\phi$ was changed in Examples A to C of the optical filter;

Figs. 7A to 7D are views for explaining the operation of the optical amplifier according to the first embodiment;

Figs. 8, 9, and 10A are schematic views showing the arrangements of optical amplifiers according to the second to fourth embodiments of the present invention, respectively, and Fig. 10B is a schematic view showing the arrangement of a modification of the fourth embodiment;

Fig. 11 is an explanatory view of an optical filter and spectrum monitor device in the third embodiment;

Fig. 12 is a schematic view showing the arrangement of an optical amplifier according to the fifth embodiment of the present invention, and

·Figs. 13A to 13C are views for explaining its operation;

Figs. 14A and· 14B are schematic views showing the arrangements of an optical amplifier according to the sixth embodiment of the present invention and its modification, respectively, Fig. 15 is a schematic view showing the arrangement of an optical amplifier according to the seventh embodiment of the present invention, and Fig. 16 is a graph which compares the noise characteristic of the seventh embodiment with that of a conventional optical amplifier;

Fig. 17 is a view for explaining the loss spectrum of a modification of an optical filter used in the optical amplifier according to the present invention; and

Fig. 18 is a schematic view showing the arrangement of an optical amplifier according to the eighth embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred Embodiments of the present invention will be described below in detail with reference to the accompanying drawings. To facilitate the comprehension of the explanation, the same reference numerals denote the same parts, where possible, throughout the drawings, and a repeated explanation

·will be omitted.

(First Embodiment)

Fig. 1 is a schematic view of an optical amplifier according to the first embodiment. In the optical amplifier 100 according to this embodiment, an optical coupler 130, input-side optical amplification section 111, optical filter 140, and output-side optical amplification section 112 are sequentially connected in series between an optical input terminal 101 and an optical output terminal 102. The optical amplifier 100 also has optical pumping light sources 121 and 122 for supplying optical pumping light to the input-side optical amplification section 111 and output-side optical amplification section 112, respectively, and a control circuit 150 for controlling the light powers from the optical pumping light sources 121 and 122 and the loss spectrum of the optical filter 140.

The optical coupler 130 demultiplexes some components of multiplexed signal light input to the optical input terminal 101, outputs the components to the control circuit 150, and outputs the remaining components to the input-side optical amplification section 111. The input-side optical amplification section 111 receives optical pumping light from the optical pumping light source 121, optically amplifies the multiplexed signal light sent from the optical

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coupler 130 at once, and outputs the signal light. The
optical filter 140 has a loss spectrum in which the
total loss is almost constant in the wavelength band of
the multiplexed signal light, and the gradient of loss

5   with respect to the wavelength is variable in the
wavelength band. The output-side optical amplification
section 112 receives optical pumping light from the
optical pumping light source 122, optically amplifies
the multiplexed signal light sent from the optical

10   filter 140 at once, and outputs the signal light to the
optical output terminal 102.

The control circuit 150 detects the power of
multiplexed signal light demultiplexed by the optical
coupler 130. The control circuit 150 controls the

15   power of optical pumping light to be output from the
optical pumping light sources 121 and 122 on the basis
of the power of input multiplexed signal light such
that the power of output multiplexed signal light
obtains a predetermined target value. The control

20   circuit 150 also controls the loss spectrum of the
optical filter 140 on the basis of the power of input
multiplexed signal light.

Fig. 2 is an explanatory view of the input-side
optical amplification section 111 and optical pumping

25   light source 121. The input-side optical amplification
section 111 includes an amplification optical fiber 113,

·optical coupler 114, and optical isolators 115 and 116. The optical coupler 114 sends optical pumping light output from the optical pumping light source 121 to the amplification optical fiber 113 and also passes signal

5   light output from the amplification optical fiber 113. The optical isolators 115 and 116 pass light in the forward direction but do not pass light in the reverse direction.

        The amplification optical fiber 113 is an optical

10   waveguide doped with a fluorescent material that can be excited by optical pumping light output from the optical pumping light source 121. The fluorescent material to be doped is preferably a rare earth element and, more preferably, Er. Er is preferably doped

15   because signal light in a 1.55-μm band can be optically amplified. At this time, the wavelength of optical pumping light to be output from the optical pumping light source 121 and supplied to the amplification optical fiber 113 is preferably 1.48 μm or 0.98 μm.

20   The output-side optical amplification section 112 and optical pumping light source 122 have the same arrangement as described above.

        A preferred example of the optical filter 140 will be described next. Fig. 3 is an explanatory view of

25   the optical filter 140. This optical filter 140 is a planar lightwave circuit formed on a substrate 10 made

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of, e.g., quartz, and comprises a main optical path 20, first sub optical path 21, second sub optical path 22, heater 51 serving as a first temperature adjustment means, and heater 53 serving as a second temperature

5   adjustment means.

The main optical path 20 is an optical waveguide for guiding light incident on an optical input terminal 11 at one end face of the substrate 10 to an optical output terminal 12 at the other end face of the

10   substrate 10 and causes the light to emerge therefrom. The main optical path 20 has six regions A to F.

The main optical path 20 and first sub optical path 21 are close and optically coupled to each other in the first region A and third region C, thereby

15   forming a first optical coupler 31 and second optical coupler 32. In the second region B, the optical path length of the main optical path 20 is set to be longer than that of the first sub optical path 21, so the two optical paths are spaced apart from each other. Thus,

20   the portion of the main optical path from the first region A to the third region C and the first sub optical path 21 construct an asymmetrical Mach-Zehnder interference circuit. This portion will be referred to as a first Mach-Zehnder interference circuit 41

25   hereinafter.

Similarly, the main optical path 20 and second sub

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·optical path 22 are close and optically coupled to each other in the fourth region D and sixth region F, thereby forming a third optical coupler 33 and fourth optical coupler 34. In the fifth region E, the optical

5 path length of the main optical path 20 is set to be shorter than that of the first sub optical path 21, so the two optical paths are spaced apart from each other. Thus, the portion of the main optical path from the fourth region D to the sixth region F and the second

10 sub optical path 22 construct an asymmetrical Mach-Zehnder interference circuit. This portion will be referred to as a second Mach-Zehnder interference circuit 42 hereinafter.

The heater 51 is formed on the second region B of

15 the main optical path 20. This heater 51 adjusts the temperature of the main optical path 20 to adjust the optical path length difference between the main optical path 20 and the first sub optical path 21 in the first Mach-Zehnder interference circuit 41, thereby adjusting

20 the transmission characteristic of the first Mach-Zehnder interference circuit 41. The heater 53 is formed on the fifth region E of the main optical path 20. This heater 53 adjusts the temperature of the main optical path 20 to adjust the optical path length

25 difference between the main optical path 20 and the second sub optical path 22 in the second Mach-Zehnder

·interference circuit 42, thereby adjusting the transmission characteristic of the second Mach-Zehnder interference circuit 42. The heaters 51 and 53 are controlled by the control circuit 150.

5   Heaters may be provided on the second region B of the first sub optical path 21 and on the fifth region E of the second sub optical path 22 in place of the heaters 51 and 53. Alternatively, heaters may be provided on both the main optical path and the first

10   and second sub optical paths. Instead of the heaters, Peltier elements for cooling may be provided.

In this optical filter 1, a loss spectrum $L(\lambda)$ [dB] for light input to the optical input terminal 11 and output from the optical output terminal 12 through

15   the main optical path 20 depend on both a transmittance characteristic $T_1(\lambda)$ of the first Mach-Zehnder interference circuit 41 based on optical coupling between the main optical path 20 and the first sub optical path 21 by the optical couplers 31 and 32 and a

20   transmittance characteristic $T_1(\lambda)$ of the second Mach-Zehnder interferometer 42 based on optical coupling between the main optical path 20 and the second sub optical path 22 by the optical couplers 33 and 34.

25   Generally, a transmittance characteristic $T(\lambda)$ of an asymmetrical Mach-Zehnder interference circuit is

given by

$$T(\lambda) = 1 - A\sin^2\left(\frac{2\pi(\lambda - \lambda_0)}{\Delta\lambda} + \Delta\phi\right) \qquad (1)$$

where λ [nm] is the wavelength of light, A, λ_0 [nm], and $\Delta\lambda$ [nm] are constants determined by the structural parameters of the Mach-Zehnder interference circuit, and $\Delta\phi$ is the phase value that can be set by temperature adjustment. A loss spectrum $L(\lambda)$ of the optical filter 1 is given by

$$L(\lambda) = -10\log\{T_1(\lambda) \cdot T_2(\lambda)\} \qquad (2)$$

A gradient $dL(\lambda)/d\lambda$ of the loss spectrum $L(\lambda)$ of the optical filter 1 with respect to the wavelength will be simply referred to as a gradient $S(\lambda)$ hereinafter.

When the constants A, λ_0, and $\Delta\lambda$ of each of the first Mach-Zehnder interference circuit 41 and second Mach-Zehnder interference circuit 42 are appropriately designed, and the phase value $\Delta\phi$ is changed by temperature adjustment by the heaters 51 and 53 while maintaining an almost constant loss $L(\lambda_1)$ at a predetermined wavelength λ_1 in a predetermined wavelength band, the loss $L(\lambda)$ and gradient $S(\lambda)$ in the wavelength band can be changed. As will be described later, the gradient $S(\lambda)$ of the optical filter 1 has small dependence on the wavelength λ, and the linearity of the loss $L(\lambda)$ of the optical filter 1 with respect to the wavelength λ is excellent.

The present inventor prepared several types of optical filters 1 by changing the structural parameters of the Mach-Zehnder interferometers 41 and 42 and confirmed the variability of the gradient $S(\lambda)$. The

5 result will be described below.

A table below show the structural parameters in examples.

		Example A	Example B	Example C
First Mach-Zehnder Interference Circuit	A	0.60	0.85	0.60
	λ_0	1550	1550	1590
	$\Delta\lambda$	200	200	200
Second Mach-Zehnder Interference Circuit	A	0.50	0.60	0.5
	λ_0	1600	1600	1640
	$\Delta\lambda$	200	200	200

In the optical filters of all examples, the optical path lengths in the Mach-Zehnder interference circuits 41 and 42 were set to $12.5\lambda_0$ and $9.5\lambda_0$ at

10 reference temperature. Under these conditions, the heaters 51 and 53 were operated to adjust the temperatures in the second region B and fifth region E of the main optical path 20, respectively, thereby

15 changing the phase values $\Delta\phi$ of the Mach-Zehnder interference circuits 41 and 42 within the range of 0 rad to 0.595 rad such that the phase values had opposite signs and equal absolute values.

Figs. 4 to 6 are graphs showing loss spectra

20 obtained when the phase value $\Delta\phi$ was changed in the optical filters of Examples A to C.

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As is apparent from Fig. 4, in Example A, the loss ranges from 2.37 to 3.01 dB, i.e., is almost constant near the central wavelength of 1,550 nm in the wavelength band of 1,535 to 1,565 nm, and the gradient

5        $S(\lambda)$ can be set within the range of 0 to 5.05 dB/30 nm in the wavelength band. When the phase value $\Delta\phi$ is 0.595 rad, the maximum value of the deviation from a straight line passing through a point corresponding to a loss of 2.89 dB (@central wavelength: 1,550 nm) is

10   sufficiently as small as ±0.21 dB. Thus, it was confirmed that the gradient $S(\lambda)$ is excellent in linearity.

As is apparent from Fig. 5, in Example B, the loss ranges from 3.65 to 3.98 dB, i.e., is almost constant

15   near the central wavelength of 1,550 nm in the wavelength band of 1,535 to 1,565 nm, and the gradient $S(\lambda)$ can be set within the range of 0 to 10 dB/30 nm in the wavelength band. When the phase value $\Delta\phi$ is 0.314 rad, the maximum value of the deviation from a straight

20   line passing through a point corresponding to a loss of 0.87 dB (@central wavelength: 1,550 nm) is sufficiently as small as ±0.87 dB. Thus, it was confirmed that the gradient $S(\lambda)$ is excellent in linearity.

As is apparent from Fig. 6, in Example C, the loss

25   ranges from 2.73 to 3.01 dB, i.e., is almost constant near the central wavelength of 1,590 nm in the

·wavelength band of 1,575 to 1,605 nm, and the gradient

$S(\lambda)$ can be set within the range of 0 to 5 dB/30 nm in

the wavelength band. When the phase value $\Delta\phi$ is 0.595

rad, the maximum value of the deviation from a straight

5 line passing through a point corresponding to a loss of

2.89 dB (@central wavelength: 1,590 nm) is sufficiently

as small as ±0.21 dB. Thus, it was confirmed that the

gradient $S(\lambda)$ is excellent in linearity.

When the structural parameters of the Mach-Zehnder

10 interference circuits 41 and 42 are appropriately set

such that the phase value $\Delta\phi$ is set to 0 by adjusting

the temperatures in the second region B and fifth

region E of the main optical path 20 to predetermined

bias temperatures, the phase value $\Delta\phi$ can be changed

15 within the range of 0 to +0.595 rad by making the

temperatures in the second region B and fifth region E

of the main optical path 20 higher than the bias

temperatures. In addition, the phase value $\Delta\phi$ can be

changed within the range of -0.595 to 0 rad by making

20 the temperatures in the second region B and fifth

region E of the main optical path 20 lower than the

bias temperatures. When the phase value $\Delta\phi$ is changed

within the range of -0.595 to +0.595 rad, the gradient

$S(\lambda)$ can be set within the range of $\pm a$ dB/nm in a

25 predetermined wavelength band.

When Peltier elements are used in place of the

heaters 51 and 53 to raise or lower the temperatures in the second region B and fifth region E of the main optical path 20, the phase value $\Delta\phi$ can be set not only to a positive value but also to a negative value. This also makes it possible to change the phase value $\Delta\phi$ within the range of -0.595 to +0.595 rad.

As described above, in the optical filter 140 shown in Fig. 3, the loss spectrum for light input to the optical input terminal 11 and output from the optical output terminal 12 through the main optical path 20 is determined by the transmittance characteristic of the first Mach-Zehnder interference circuit 41 based on optical coupling between the main optical path 20 and the first sub optical path 21 by the optical couplers 31 and 32 and the transmittance characteristic of the second Mach-Zehnder interferometer 42 based on optical coupling between the main optical path 20 and the second sub optical path 22 by the optical couplers 33 and 34. This optical filter 140 is preferable because it is integrated on the substrate 10 and has a compact structure and also because of its small insertion loss.

Operation of the optical amplifier 100 according to the first embodiment will be described next, and an optical amplifier control method according to the first embodiment will be described. Figs. 7A to 7D are views

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·for explaining operation of the optical amplifier 100
according to the first embodiment. As for the loss
spectrum (Fig. 7A)·of the optical filter 140, as
described above, the loss $L(\lambda_l)$ is almost constant at

5   the predetermined wavelength λ_l in the wavelength band
of signal light, and the gradient $S(\lambda)$ is variable in
the wavelength band. The gradient $S(\lambda)$ is controlled
by the control circuit 150 which monitors the input
signal light power.

10   Assume that the input signal light power has a
predetermined value, and the gain of optical
amplification of signal light by the input-side optical
amplification section 111 and output-side optical
amplification section 112 is almost constant

15   independently of the wavelength (Fig. 7B). In this
case, when the input signal light power becomes smaller
than the predetermined value, the gain of optical
amplification of signal light by the input-side optical
amplification section 111 and output-side optical

20   amplification section 112 is controlled by the control
circuit 150 and becomes large. As a consequence, the
longer the wavelength is, the smaller the gain becomes:
the gain has wavelength dependence (Fig. 7C). At this
time, however, the gradient $S(\lambda)$ of the optical filter

25   140 is controlled by the control circuit 150. The
longer the wavelength is, the smaller the loss is set.

·Hence, the wavelength dependence of gain of the

input-side optical amplification section 111 and

output-side optical amplification section 112 is

canceled by the wavelength dependence of loss of the

5   optical filter 140. As a result, the gain

characteristic of the entire optical amplifier 100

becomes almost constant independently of the wavelength,

and the gain flatness is maintained (Fig. 7D).

As described above, in this embodiment, even when

10   the input signal light power varies, the output signal

light power can be maintained at a predetermined target

value, and the gain flatness of the entire optical

amplifier 100 can be maintained. In addition, since

the loss of the optical filter 140 is almost constant

15   at a predetermined wavelength in the wavelength band of

signal light, the noise factor does not degrade. In

this embodiment, the optical filter 140 may be located

on the output side of the output-side optical

amplification section 112.

20   (Second Embodiment)

Fig. 8 is a schematic view showing the arrangement

of an optical amplifier 200 according to the second

embodiment of the present invention. Fig. 8 also

illustrates an optical amplifier 200A provided on the

25   input side of the optical amplifier 200. In the

optical amplifier 200 according to this embodiment, an

optical coupler 230, input-side optical amplification

section 211, optical filter 240, and output-side

optical amplification section 212 are sequentially

connected in series between an optical input terminal

5   201 and an optical output terminal 202. The optical

amplifier 200 also has optical pumping light sources

221 and 222 for supplying optical pumping light to the

input-side optical amplification section 211 and

output-side optical amplification section 212,

10   respectively, and a control circuit 250 for controlling

the optical pumping light sources 221 and 222 and the

loss spectrum of the optical filter 240.

The arrangement of each element is the same as in

the first embodiment except the control circuit 250.

15   The control circuit 250 detects the power of input

signal light demultiplexed by the optical coupler 230,

as in the first embodiment, and also receives

information related to the power of signal light output

from the optical amplifier 200A on the input side,

20   which is transmitted from the optical amplifier 200A on

the input side. The control circuit 250 calculates the

necessary gain on the basis of the output signal light

power of the input-side optical amplifier 200A and the

input signal light power of the optical amplifier of

25   its own and controls the powers of optical pumping

light to be output from the optical pumping light

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sources 221 and 222 such that the power of output

signal light has a predetermined target value. The

control circuit 250 also controls the loss spectrum of

the optical filter 240 on the basis of the necessary

5   gain.

More specifically, when the necessary gain becomes

large, the gain of optical amplification of signal

light by the input-side optical amplification section

211 and output-side optical amplification section 212

10   becomes smaller as the wavelength becomes long; the

gain has wavelength dependence. At this time, however,

the gradient $S(\lambda)$ of the optical filter 240 is

controlled by the control circuit 250 so that the

longer the wavelength is, the smaller the loss becomes.

15   Hence, the wavelength dependence of gain of the

input-side optical amplification section 211 and

output-side optical amplification section 212 is

canceled by the loss spectrum of the optical filter 240.

As a result, the gain characteristic of the entire

20   optical amplifier 200 becomes almost constant

independently of the wavelength, and the gain flatness

is maintained.

As described above, in this embodiment as well,

even when the input signal light power varies, the

25   output signal light power can be maintained at a target

value, and the gain flatness of the entire optical

·amplifier 200 can be maintained. In addition, since

the loss of the optical filter 240 is almost constant

at a predetermined·wavelength in the wavelength band of

signal light, the noise factor does not degrade. In

5   this embodiment, the optical filter 240 may be located

on the output side of the output-side optical

amplification section 212.

(Third Embodiment)

     Fig. 9 is a schematic view showing the arrangement

10   of an optical amplifier 300 according to the third

embodiment of the present invention. In the optical

amplifier 300 according to this embodiment, an optical

coupler 331, input-side optical amplification section

311, output-side optical amplification section 312,

15   optical filter 340, and optical coupler 332 are

sequentially connected in series between an optical

input terminal 301 and an optical output terminal 302.

The optical amplifier 300 also has optical pumping

light sources 321 and 322 for supplying optical pumping

20   light to the input-side optical amplification section

311 and output-side optical amplification section 312,

respectively, and a control circuit 350 for controlling

the optical pumping light sources 321 and 322 and the

loss spectrum of the optical filter 340.

25   The arrangement of each constituent element is the

same as in the first embodiment, and a detailed

description thereof will be omitted. As characteristic features of this embodiment, the optical coupler 332 is arranged on the light output side to supply a demultiplexed part of output light to the control circuit 350, and the optical filter 340 is arranged on the downstream side of the multi-stage optical amplifiers 311 and 312.

The control circuit 350 detects the power of input signal light demultiplexed by the optical coupler 331 and detects the power of output signal light demultiplexed by the optical coupler 332. The control circuit 350 controls the powers of optical pumping light to be output from the optical pumping light sources 321 and 322 such that the power of output signal light has a predetermined target value. The control circuit 350 calculates the gain on the basis of the output signal light power and input signal light power and controls the loss spectrum of the optical filter 340 on the basis of the gain.

More specifically, when the gain becomes large, the gain of optical amplification of signal light by the input-side optical amplification section 311 and output-side optical amplification section 312 becomes smaller as the wavelength becomes long; the gain has wavelength dependence. At this time, however, the gradient $S(\lambda)$ of the optical filter 340 is controlled

by the control circuit 350 so that the longer the

wavelength is, the smaller the loss becomes. Hence,

the wavelength dependence of gain of the input-side

optical amplification section 311 and output-side

5   optical amplification section 312 is canceled by the

loss spectrum of the optical filter 340. As a result,

the gain characteristic of the entire optical amplifier

300 becomes almost constant independently of the

wavelength, and the gain flatness is maintained.

10   As described above, in this embodiment as well,

even when the input signal light power varies, the

output signal light power can be maintained at a target

value, and the gain flatness of the entire optical

amplifier 300 can be maintained. In addition, since

15   the loss of the optical filter 340 is almost constant

at a predetermined wavelength in the wavelength band of

signal light, the noise factor does not degrade. In

this embodiment, the optical filter 340 may be located

between the input-side optical amplification section

20   311 and the output-side optical amplification section

312.

(Fourth Embodiment)

Fig. 10A is a schematic view showing the

arrangement of an optical amplifier 400 according to

25   the fourth embodiment of the present invention. In the

optical amplifier 400 according to this embodiment, an

input-side optical amplification section 411,

output-side optical amplification section 412, and

optical filter 440 are sequentially connected in series

between an optical input terminal 401 and an optical

5   output terminal 402.   The optical amplifier 400 also

has optical pumping light sources 421 and 422 for

supplying optical pumping light to the input-side

optical amplification section 411 and output-side

optical amplification section 412, respectively, a

10   spectrum monitor device 460 for monitoring the powers

of signal light components with respective wavelengths,

which are output from the optical output terminal 402,

and a control circuit 450 for controlling the optical

pumping light outputs from the optical pumping light

15   sources 421 and 422 and the loss spectrum of the

optical filter 440.

        As a characteristic feature of this embodiment,

the spectrum monitor device 460 is used.   The

arrangements of the remaining elements are the same as

20   in the above embodiments, and a detailed description

thereof will be omitted.

        Part of light output from the optical output

terminal 402 is demultiplexed and guided to the

spectrum monitor device 460, or light output from a

25   second sub optical path 22 of the optical filter 440

having the structure shown in Fig. 3 is guided to the

spectrum monitor device 460, and the guided light is demultiplexed by the spectrum monitor device 460. This spectrum monitor device 460 can be implemented by, e.g., an AWG (Arrayed-Waveguide Grating). In this case, the

5   spectrum monitor device 460 can be formed on a common substrate together with the optical filter 440 having the structure shown in Fig. 3, so the entire device can be downsized.

    The control circuit 450 controls the power of

10   output signal light component with respective wavelengths, which are demultiplexed by the spectrum monitor device 460. The control circuit 450 controls the powers of optical pumping light to be output from the optical pumping light sources 421 and 422 such that

15   the power of output signal light has a predetermined target value. The control circuit 450 also controls the loss spectrum of the optical filter 440 on the basis of any deviation between the powers of output signal light components with respective wavelengths

20   such that the deviation becomes small.

    Preferred examples of the optical filter 440 and spectrum monitor device 460 will be described. Fig. 11 is an explanatory view of the optical filter 440 and spectrum monitor device 460. The optical filter 440

25   and spectrum monitor device 460 are formed on a common substrate 10A. The optical filter 440 has the same

structure as that shown in Fig. 3. The spectrum

monitor device 460 is formed from an AWG formed on the

substrate 10A. More specifically, the spectrum monitor

device 460 has an input-side slab waveguide 61, array

5   waveguide section 62 having a plurality of channel

waveguides, output-side slab waveguide 63, and

output-side channel waveguides 64_1 to 64_N.

Light output from the second sub optical path 22

of the optical filter 440 is input to the input-side

10   slab waveguide 61. The light is demultiplexed and

output to the channel waveguides of the array waveguide

section 62. The plurality of channel waveguides of the

array waveguide section 62 have different optical path

lengths from the input-side slab waveguide 61 to the

15   output-side slab waveguide 63 and give different phases

to the light to be guided. The output-side slab

waveguide 63 receives light from each of the plurality

of channel waveguides of the array waveguide section 62

and outputs the light to each of the output-side

20   channel waveguides 64_1 to 64_N.

The light components output to the output-side

channel waveguides 64_1 to 64_N are signal light components

having respective wavelengths, which are obtained by

demultiplexing the light output from the second sub

25   optical path 22 of the optical filter 440. The control

circuit 450 detects the powers of signal light

components having respective wavelengths, which are output to the output-side channel waveguides 64_1 to 64_N of the spectrum monitor device 460, and controls the loss gradient of the optical filter 440 such that the

5 deviation between the powers of signal light components having respective wavelengths becomes small. The control circuit 450 may control the loss gradient of the optical filter 440 such that the deviation between powers of two signal light components having respective

10 wavelengths (e.g., the maximum wavelength and minimum wavelength) in the signal light components having respective wavelengths, which are demultiplexed by the spectrum monitor device 460.

Fig. 10B shows a modification to the fourth

15 embodiment. A difference from the fourth embodiment shown in Fig. 10A is that an optical coupler 430 for demultiplexing a monitor light component in the input signal light is arranged on the optical input terminal 401 side. Monitor light contains, e.g., information

20 related to the shortest wavelength and longest wavelength in the sent multiplexed signal light. The control circuit 450 reads the pieces of information and determines the two wavelengths for which the power deviation is to be obtained.

25 As described above, in this embodiment as well, even when the input signal light power varies, the

output signal light power can be maintained at a
predetermined target value, and the gain flatness of
the entire optical amplifier 400 can be maintained.   In
addition, since the loss of the optical filter 440 is

5   almost constant at a predetermined wavelength in the
wavelength band of signal light, the noise factor does
not degrade.   Furthermore, in this embodiment, since
the loss gradient of the optical filter 440 is
feedback-controlled, stable operation is possible.

10   (Fifth Embodiment)

Fig. 12 a schematic view showing the arrangement
of an optical amplifier 500 according to the fifth
embodiment of the present invention.   In the optical
amplifier 500 according to this embodiment, a gain

15   equalizer 170 is inserted between an input-side optical
amplification section 111 and an optical filter 140 of
the optical amplifier 100 according to the first
embodiment.   The gain equalizer 170 equalizes gain
wavelength dependence unique to the input-side optical

20   amplification section 111 and output-side optical
amplification section 112.   This gain equalizer 170 can
be implemented by, e.g., an optical fiber grating
element having index modulation in the core of an
optical fiber or an etalon filter having a Fabry-Perot

25   resonator structure.

The operation of the optical amplifier 500

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according to the fifth embodiment, i.e., an optical
amplification method according to the fifth embodiment
will be described next. Figs. 13A to 13C are views for
explaining the operation of the optical amplifier 500

5   according to the fifth embodiment. Even when the input
signal light power has a predetermined value, the gain
spectrum of the input-side optical amplification
section 111 and output-side optical amplification
section 112 is not strictly constant and has a gain

10   wavelength dependence unique to the input-side optical
amplification section 111 and output-side optical
amplification section 112 (Fig. 13A). The gain
equalizer 170 has a loss spectrum having the same shape
as that of the gain spectrum of the input-side optical

15   amplification section 111 and output-side optical
amplification section 112 at this time. Hence, the
spectrum of output light is flat.

       When the input signal light power has a value
smaller than the predetermined value, the gain of

20   optical amplification of signal light by the input-side
optical amplification section 111 and output-side
optical amplification section 112 is controlled by a
control circuit 150 and becomes large. Consequently,
the longer the wavelength becomes, the smaller the gain

25   becomes, so the wavelength dependence of gain changes
(Fig. 13B). At this time, however, the loss spectrum

of the optical filter 140 is controlled and set by the control circuit 150 such that the longer the wavelength is, the smaller the gain becomes.

For the light output from the input-side optical amplification section 111 and output-side optical amplification section 112, the gain wavelength dependence unique thereto is equalized by the gain equalizer 170, so the gain (dB) is adjusted to linearly change with respect to the wavelength, as shown in Fig. 13C. After that, the remaining wavelength dependence of gain is canceled by the loss spectrum of the optical filter 140. As a result, the gain characteristic of the entire optical amplifier 500 is almost constant independently of the wavelength, and its flatness is maintained.

As described above, in this embodiment as well, even when the input signal light power varies, the output signal light power can be maintained at a predetermined target value, and the gain flatness of the entire optical amplifier 500 can be maintained. Especially in this embodiment, since the gain equalizer 170 is provided in addition to the optical filter 140, the gain flatness of the entire optical amplifier 500 is excellent. In addition, since the loss of the optical filter 140 is almost constant at a predetermined wavelength in the wavelength band of

·signal light, the noise factor does not degrade. In

this embodiment, one or both of the optical filter 140

and gain equalizer·170 may be located on the output

side of the output-side optical amplification section

5   112. The same effect as described above can be

obtained even when a gain equalizer is inserted in any

one of the optical amplifiers according to the second

to fourth embodiments.

(Sixth Embodiment)

10   Fig. 14A is a schematic view showing the

arrangement of an optical amplifier 300a according to

the sixth embodiment of the present invention. The

optical amplifier 300a according to this embodiment is

different from the optical amplifier 300 according to

15   the third embodiment shown in Fig. 9 only in that an

ASE light level detector 333 is arranged in place of

the optical coupler 332 at the final stage.

The ASE light level detector 333 detects the level

of spontaneous emission light (ASE light) having

20   respective wavelengths located outside the two ends of

a predetermined wavelength band of signal light output

from an optical filter 340. A control circuit 350

adjusts the loss spectrum of the optical filter 340

such that the difference in the detected ASE light

25   level between the longest wavelength side and the

shortest wavelength side is maintained at a

predetermined value. Use of the level difference in

ASE light advantageously facilitates control.

When monitor light having information related to

the shortest wavelength and longest wavelength in

5   multiplexed signal light is sent together with the

multiplexed signal light, monitor light demultiplexed

by an optical coupler 331 is received by the control

circuit 350 to read the pieces of information, and

wavelengths for which the ASE light levels are to be

10   detected by the ASE light level detector 333 are set to

those outside the read shortest wavelength and longest

wavelength. In this case, even when the shortest

wavelength and longest wavelength in the multiplexed

signal light are not constant, stable optical

15   amplification can be performed.

Fig. 14B is a schematic view showing the

arrangement of an optical amplifier 600 as a

modification to the sixth embodiment of the present

invention. More specifically, an optical coupler 630,

20   input-side optical amplification section 611,

output-side optical amplification section 612, optical

coupler 631, and optical filter 640 are sequentially

connected in series between an optical input terminal

601 and an optical output terminal 602. The optical

25   amplifier 600 also has optical pumping light sources

621 and 622 for supplying optical pumping light to the

input- and output-side optical amplification sections 611 and 112, respectively, and a control circuit 650 for controlling the light powers of the optical pumping light sources 621 and 622 and the loss spectrum of the optical filter 640. Light demultiplexed by the optical coupler 631 is guided to a spectrum monitor device 660 and variable bandpass filter 670. The light transmitted through the variable bandpass filter 670 is detected by a light-receiving element 680. The arrangements of the amplification sections 611 and 612 and the optical filter 640 are the same as in the first embodiment, and a detailed description thereof will be omitted.

In this embodiment, the wavelengths of light with the shortest wavelength and light with the longest wavelength in the signal light are detected by the spectrum monitor device 660. By controlling the variable bandpass filter 670, the ASE light levels on the shorter wavelength side of the detected shortest wavelength and on the longer wavelength side of the detected longest wavelength are detected by the light-receiving element 680. The control circuit 650 adjusts the loss spectrum of the optical filter 640 such that the difference in detected ASE light levels between the longer wavelength side and the shorter wavelength side is maintained at a predetermined value.

· This also facilitates control.

(Seventh Embodiment)

Fig. 15 is a schematic view showing the arrangement of an optical amplifier 700 according to the seventh embodiment of the present invention. This optical amplifier 700 incorporates a DCF (Dispersion Compensating Fiber) 770.

More specifically, an optical coupler 730, input-side optical amplification section 711, optical filter 740, intermediate optical amplification section 712, gain equalizer 760, DCF 770, and output-side optical amplification section 713 are sequentially connected in series between an optical input terminal 701 and an optical output terminal 702. The optical amplifier 700 also has optical pumping light sources 721 to 723 for supplying optical pumping light to the input-side, intermediate, and output-side optical amplification sections 711 to 713, respectively, and a control circuit 750 for controlling the light powers of the optical pumping light sources 721 to 723 and the loss spectrum of the optical filter 740. The arrangements of the optical amplification sections 711 to 713 and optical filter 740 are the same as in the first embodiment, and a detailed description thereof will be omitted.

To confirm the noise characteristic improving

·effect of the optical amplifier 700 according to this
embodiment using an optical filter capable of adjusting
the loss spectrum,'the present inventor conducted
comparative experiments for a case wherein a

5   conventional variable optical attenuator for adjusting
only the total loss ratio is used as an optical filter.

In the experiments, the noise characteristic with
respect to the input level in a dynamic range of 16 dB
from -28 dbm/ch to -12 dbm/ch was measured. When the

10   variable optical attenuator is used, it is generally
difficult to cope with an input dynamic range of 16 dB.
Hence, measurement was performed by dividing the range
into two parts: -28 dbm/ch to -20 dbm/ch and -20 dbm/ch
to -12 dbm/ch, and also for a combination thereof.

15   Fig. 16 shows the measurement results. Referring
to Fig. 16, ○ indicates a noise characteristic with
respect to the input level, which was obtained when the
total range was amplified by one type of optical
amplifier using the variable optical attenuator, △

20   indicates a noise characteristic with respect to the
input level, which was obtained when the total range
was divided and amplified by two types of optical
amplifiers using the variable optical attenuator, and □
indicates a noise characteristic with respect to the

25   input level, which was obtained when the total range
was amplified by the optical amplifier according to the

seventh embodiment of the present invention.

It was confirmed that the optical amplifier according to the present invention has an effect for improving the noise characteristic at all input levels and widening the adaptable dynamic range.

A modification of the optical filter will be described next. Each of the optical filters having the loss spectra shown in Figs. 4 to 6 has an almost constant loss near the central wavelength of the use wavelength band. However, the wavelength λ_1 at which the loss becomes almost constant may be shifted to the shorter wavelength side or longer wavelength side. For an optical filter having a loss spectrum shown in Fig. 17, the wavelength λ_1 is located at the shortest wavelength in the wavelength band. The loss spectrum can be changed between and $L_0(\lambda)$ and $L_2(\lambda)$. When the power of light input to the optical filter is maximum, the loss spectrum is adjusted to $L_2(\lambda)$. When the power of input light is minimum, the loss spectrum is adjusted to $L_0(\lambda)$ at which the loss becomes constant independently of the wavelength. For intermediate power, the loss spectrum is adjusted to $L_1(\lambda)$. Thus, degradation in noise factor especially in the short wavelength region can be suppressed. When the input power is minimum, the transmittance is maximized. Hence, the noise characteristic improving effect

becomes conspicuous especially when the power of input

light is small.

(Eighth Embodiment)

Fig. 18 is a schematic view showing the

5　arrangement of an optical amplifier 300b according to

the eighth embodiment of the present invention. The

optical amplifier 300b according to this embodiment is

different from the optical amplifier 300 of the third

embodiment shown in Fig. 9 in that a wave number

10　monitor 335 for detecting the number of signal light

components (wave number) contained in output

multiplexed signal light is arranged at the

demultiplexed side of an optical coupler 332 at the

final stage.

15　When the number of waves contained in input

multiplexed signal light varies, the power of the input

multiplexed signal light varies, though the powers of

individual signal light components do not vary. For

this reason, when the power of output multiplexed

20　signal light after amplification is to be simply

maintained at a predetermined value, the powers of

individual signal light components increase in case of

a decrease in wave number, or the powers of individual

signal light components decrease in case of an increase

25　in wave number, resulting in variation.

In this embodiment, the target value of power of

·output multiplexed signal light is adjusted by a

control circuit 350b in proportion to the wave number

on the basis of the output from the wave number monitor

335. Thus, even when the wave number varies, the light

5   power after the individual signal light components are

amplified can be maintained at a predetermined value.

The present invention is not limited to the above

embodiments, and various changes and modifications can

be made. For example, the fluorescent material to

10   doped into the amplification optical fiber is not

limited to Er, and another rare earth element (e.g., Tm,

Pr, Nd, or the like) may be used. Instead of the

amplification optical fiber, a planar optical waveguide

doped with a fluorescent material that can be excited

15   by optical pumping light may be used. The optical

amplifier need not always be divided into the

input-side optical amplification section and

output-side optical amplification section and may have

three or more optical amplification sections.

20

WHAT IS CLAIMED IS:

1.   An optical amplifier for amplifying, at once, multiplexed signal light belonging to a predetermined wavelength band, in which a plurality of signal light components having different wavelengths are multiplexed, comprising:

one or a plurality of optical amplification sections each of which has an optical waveguide doped with a fluorescent material and amplifies the multiplexed signal light by optical pumping of the fluorescent material;

an optical pumping light source for supplying predetermined optical pumping light to said optical amplification section;

an optical filter capable of changing a gradient $dL/d\lambda$ of a loss L (dB) with respect to a wavelength λ (nm) in the predetermined wavelength band; and

control means for controlling an optical pumping light output from said optical pumping light source such that light power after amplification has a predetermined target value, and for adjusting a characteristic of said optical filter to adjust a final gain characteristic.

2.   An amplifier according to claim 1, wherein said optical filter satisfies

$$L \approx a(\lambda - \lambda c) + b$$

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(where λc (nm) and b (dB) are constants) in the predetermined wavelength band and changes a (dB/nm) to adjust the gradient $dL/d\lambda$.

3. An amplifier according to claim 1, further comprising a gain equalizer for compensating for an inherent wavelength-dependent gain of said optical amplification section.

4. An amplifier according to claim 1, further comprising a wave number monitor for detecting the number of signal light components contained in the multiplexed signal light, and wherein said control means adjusts the target value of light power after amplification in accordance with the number of signal light components detected by said wave number monitor.

5. An amplifier according to claim 1, further comprising input light power detection means for detecting the light power input to said optical amplification section, and wherein said control means adjusts the gradient $dL/d\lambda$ of said optical filter on the basis of the detection result by said input light power detection means.

6. An amplifier according to claim 1, further comprising gain detection means for detecting a gain of said optical amplification section, and wherein said control means adjusts the gradient $dL/d\lambda$ of said optical filter on the basis of the detection result by

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said gain detection means.

7. An amplifier according to claim 1, further comprising detection means for detecting each wavelength and power of signal light components contained in the light output from said optical amplification section, and wherein said control means adjusts the gradient dL/dλ of said optical filter on the basis of power deviation between two signal light components having shortest and longest wavelengths detected by said detection means.

8. An amplifier according to claim 7, further comprising read means for reading information related to the shortest and longest wavelengths of the signal light components in the multiplexed signal light sent together with the multiplexed signal light, and wherein said control means obtains the power deviation on the basis of the information obtained by said read means.

9. An amplifier according to claim 1, further comprising ASE light level detection means for detecting an ASE light levels of the light output from said optical amplification section at each wavelengths outside two ends of the predetermined wavelength band, and wherein said control means adjusts the gradient dL/dλ of said optical filter so that a level difference between ASE light levels detected by said ASE light level detection means becomes constant.

10. An amplifier according to claim 1, further comprising:

detection means for detecting each wavelength and power of signal light components contained in the light output from said optical amplification section; and

ASE light level detection means for detecting an ASE light levels of the light output from said optical amplification section at each wavelengths one of which is shorter than the shortest wavelength and the other of which is longer than the longest wavelength both of which detected by said detection means, and

wherein said control means adjusts the gradient $dL/d\lambda$ of said optical filter so that a level difference between ASE light levels detected by said ASE light level detection means becomes constant.

11. An amplifier according to claim 10, further comprising read means for reading information related to the shortest and longest wavelengths of the signal light components in the multiplexed signal light sent together with the multiplexed signal light, and wherein said ASE light level detection means determines wavelengths to be detected on the basis of the information obtained by said read means.

12. An amplifier according to claim 2, wherein λc of said optical filter is set in the predetermined wavelength band.

13. An amplifier according to claim 1, wherein said optical filter comprises:

a main optical path which guides the multiplexed signal light and is divided into first to sixth regions

5   sequentially from an upstream side;

a first sub optical path which is arranged close to the first and third regions of the main optical path so that optical coupling of propagation light occurs, is spaced apart from the second region of the main

10   optical path so that optical coupling of the propagation light does not occur, and has a region corresponding to the second region of the main optical path, the region having a length different from that of the main optical path;

15   a second sub optical path which is arranged close to the fourth and sixth regions of the main optical path so that optical coupling of the propagation light occurs, is spaced apart from the fifth region of the main optical path so that optical coupling of the

20   propagation light does not occur, and has a region corresponding to the fifth region of the main optical path, the region having a length different from that of the main optical path;

a first temperature adjusting device arranged in

25   at least one of the second region of the main optical path and the region of the first sub optical path,

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which corresponds to the second region of the main

optical path; and

a second temperature adjusting device arranged in

at least one of the fifth region of the main optical

5   path and the region of the second sub optical path,

which corresponds to the fifth region of the main

optical path.

14. An optical amplification method of amplifying,

at once, multiplexed signal light belonging to a

10   predetermined wavelength band, in which a plurality of

signal light components having different wavelengths

are multiplexed, comprising the steps of:

guiding the multiplexed signal light to an optical

waveguide doped with a fluorescent material together

15   with predetermined optical pumping light and optically

amplifying the multiplexed signal light;

guiding at least one of the multiplexed signal

light before amplification and that after amplification

to an optical filter capable of changing a gradient

20   $dL/d\lambda$ of a loss L (dB) with respect to a wavelength λ

(nm) in the predetermined wavelength band and adjusting

the gradient $dL/d\lambda$ of the optical filter to reduce a

wavelength-dependent gain in the optical amplification;

and

25   adjusting an intensity of the optical pumping

light to adjust light power after amplification to a

predetermined target value.

15. A method according to claim 14, wherein the optical filter satisfies

$$L \approx a(\lambda - \lambda c) + b$$

(where λc (nm) and b (dB) are constants) in the predetermined wavelength band and changes a (dB/nm) to adjust the gradient $dL/d\lambda$.

16. A method according to claim 14, further comprising the step of reducing an inherent wavelength-dependent gain in the optical amplification using a predetermined gain equalizer.

17. A method according to claim 14, further comprising the step of detecting the number of signal light components contained in the multiplexed signal light and adjusting the target value of light power after amplification in accordance with the detected number of signal light components.

18. A method according to claim 14, further comprising the step of adjusting the gradient $dL/d\lambda$ of the optical filter on the basis of light power of the multiplexed signal light before the optical amplification.

19. A method according to claim 14, further comprising the step of adjusting the gradient $dL/d\lambda$ of the optical filter on the basis of the gain in the optical amplification.

20. A method according to claim 14, further comprising the step of adjusting the gradient dL/dλ of the optical filter on the basis of deviation of light power between two different wavelengths detected in the predetermined wavelength band of the light after the optical amplification.

21. A method according to claim 20, further comprising the step of reading information related to shortest and longest wavelengths of the signal light components in the multiplexed signal light sent together with the multiplexed signal light, and wherein the two different wavelengths are the read shortest and longest wavelengths.

22. A method according to claim 14, further comprising detecting ASE light levels of each of wavelengths outside two ends of the predetermined wavelength band of the light after optical amplification and adjusting the gradient dL/dλ of the optical filter so that a difference between two ASE light levels becomes constant.

23. A method according to claim 14, further comprising the step of detecting each wavelength and power of signal light components contained in the light after the optical amplification and detecting ASE light levels at each wavelengths one of which is shorter than the shortest detected wavelength and the other of which

is longer than the longest detected wavelength.

24. A method according to claim 23, further comprising the step of reading information related to shortest and longest wavelengths of the signal light

5   components in the multiplexed signal light sent together with the multiplexed signal light, and determining two wavelengths to be ASE light levels detected, on the basis of the read shortest wavelength and longest wavelength.

10   25. A method according to claim 14, wherein λc of the optical filter is set and adjusted in the predetermined wavelength band.

26. A method according to claim 14, further comprising when a total transmittance in the

15   predetermined wavelength band of the optical filter is adjusted to a maximum value, adjusting the loss L to be substantially constant independently of the wavelength.

27. A method according to claim 14, wherein the optical filter comprises:

20   a main optical path which guides the multiplexed signal light and is divided into first to sixth regions sequentially from an upstream side;

a first sub optical path which is arranged close to the first and third regions of the main optical path

25   so that optical coupling of propagation light occurs, is spaced apart from the second region of the main

· optical path so that optical coupling of the propagation light does not occur, and has a region corresponding to the second region of the main optical path, the region having a length different from that of

5 the main optical path;

a second sub optical path which is arranged close to the fourth and sixth regions of the main optical path so that optical coupling of the propagation light occurs, is spaced apart from the fifth region of the

10 main optical path so that optical coupling of the propagation light does not occur, and has a region corresponding to the fifth region of the main optical path, the region having a length different from that of the main optical path, and

15 said adjusting the gradient $dL/d\lambda$ of the optical filter is achieved by adjusting at least one of a temperature in the first sub optical path and a temperature in a region of the main optical path which corresponds to the first sub optical path, and at least

20 one of a temperature in the second sub optical path and a temperature in a region of the main optical path which corresponds to the second sub optical path.

ABSTRACT OF THE DISCLOSURE

A optical filter has a loss spectrum whose gradient $dL/d\lambda$ of a loss L (dB) with respect to the wavelength λ (nm) is variable in the wavelength band of multiplexed signal light. A control circuit detects each power of signal light components demultiplexed by an optical coupler and controls the power of optical pumping light to be supplied to an optical amplification section from an optical pumping light sources such that the power of output signal light has a predetermined target value. The control circuit also controls the gradient $dL/d\lambda$ of the optical filter on the basis of powers of the signal light components.
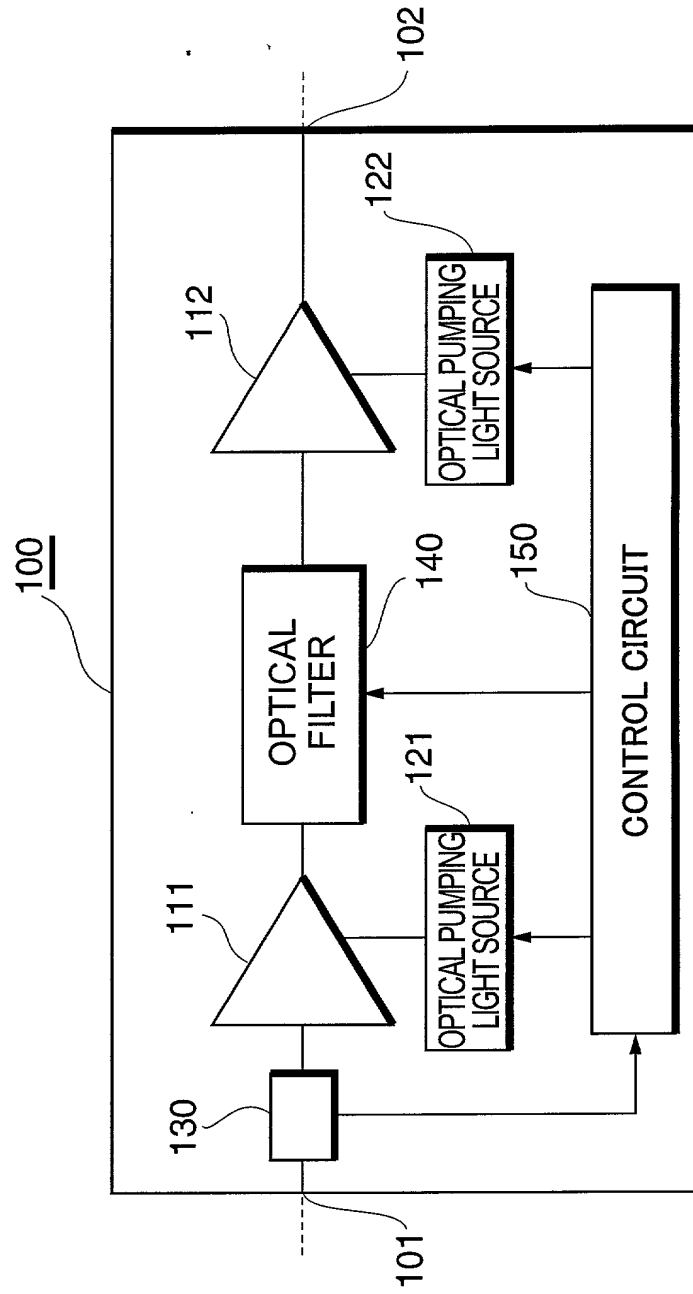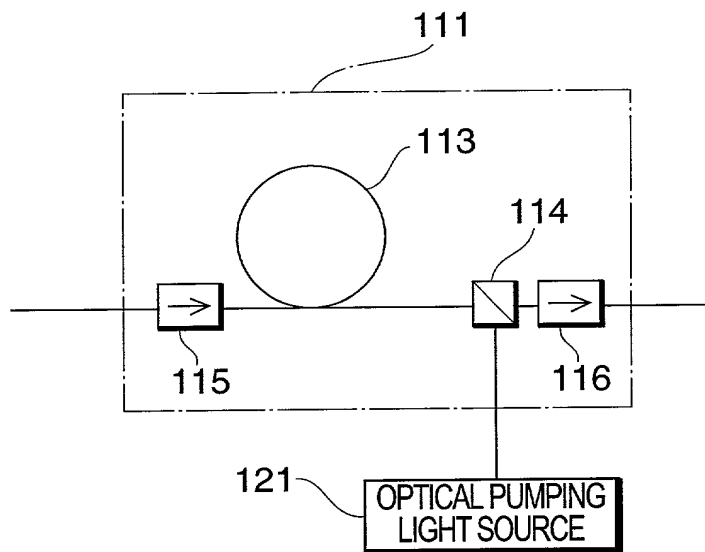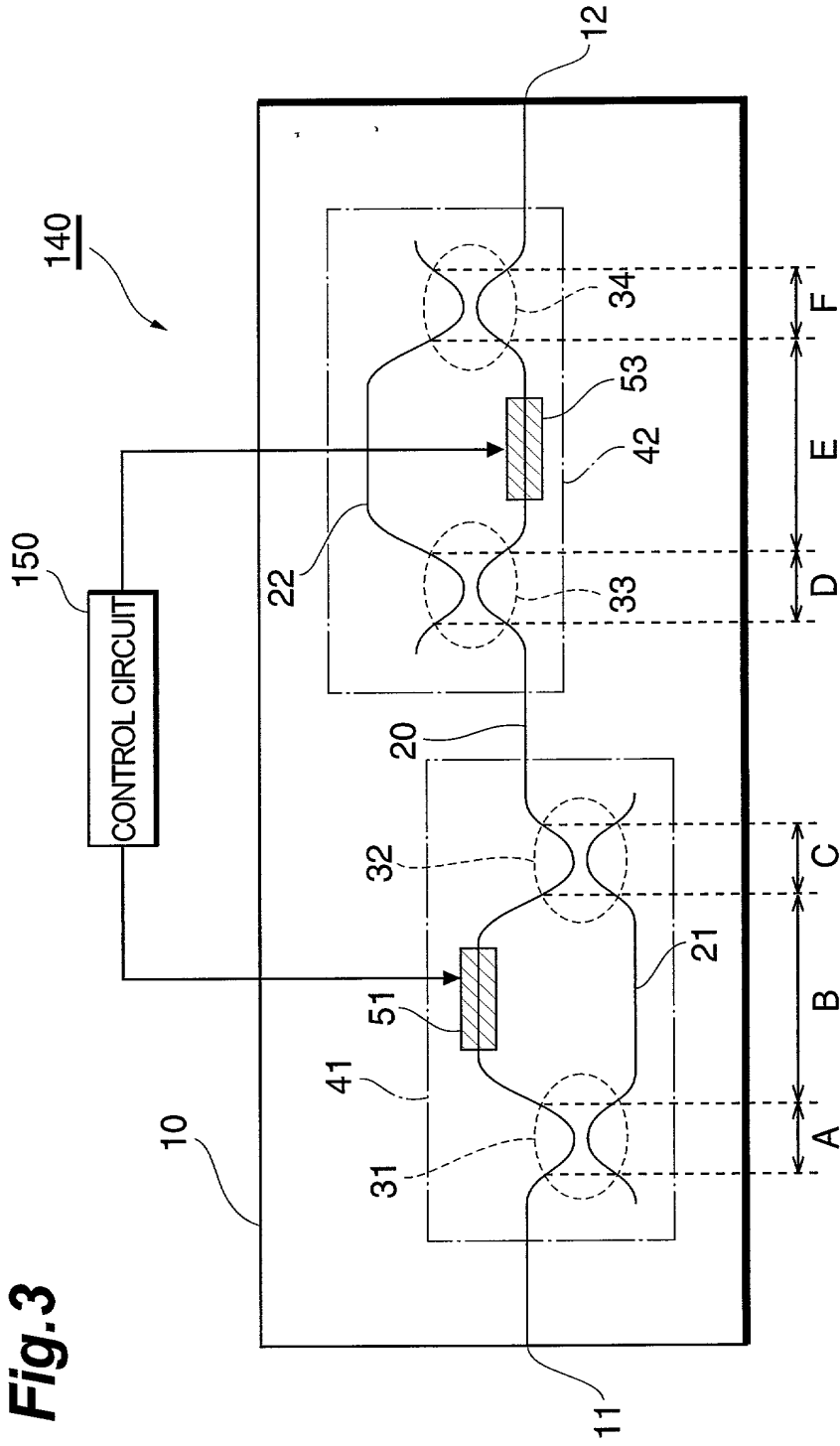
Fig.1

Fig.2

111

113

114

115   116

121   OPTICAL PUMPING
       LIGHT SOURCE

Fig.3

Fig.4

Fig.5

Fig.6

Fig.7A

LOSS (dB)

GAIN DECREASES

GAIN INCREASES

1530   WAVELENGTH (nm)   1570

Fig.7B

GAIN

WAVELENGTH

GAIN INCREASES

Fig.7C

GAIN

WAVELENGTH

Fig.7D

GAIN

WAVELENGTH

Fig.8

- 200A OPTICAL AMPLIFIER
- 201
- 200
- 230
- 211
- 221 OPTICAL PUMPING LIGHT SOURCE
- 240 OPTICAL FILTER
- 212
- 222 OPTICAL PUMPING LIGHT SOURCE
- 202
- 250 CONTROL CIRCUIT

Fig.9

Fig.10A

Fig.10B

Fig.11

Fig.12

Fig.13A

GAIN

WAVELENGTH

Fig.13B

GAIN

WAVELENGTH

Fig.13C

GAIN

WAVELENGTH

Fig.14A

Fig.14B

Fig.15

700

701

702

711 712 713

721 722 723

730 740 760 770

750

OPTICAL PUMPING LIGHT SOURCE

OPTICAL PUMPING LIGHT SOURCE

OPTICAL PUMPING LIGHT SOURCE

CONTROL CIRCUIT

Fig.16

Fig.17

LOSS(dB)

$L_2(\lambda)$

$L_1(\lambda)$

$L_0(\lambda)$

WAVELENGTH(nm)

Fig.18

Attorney's Docket No. _____
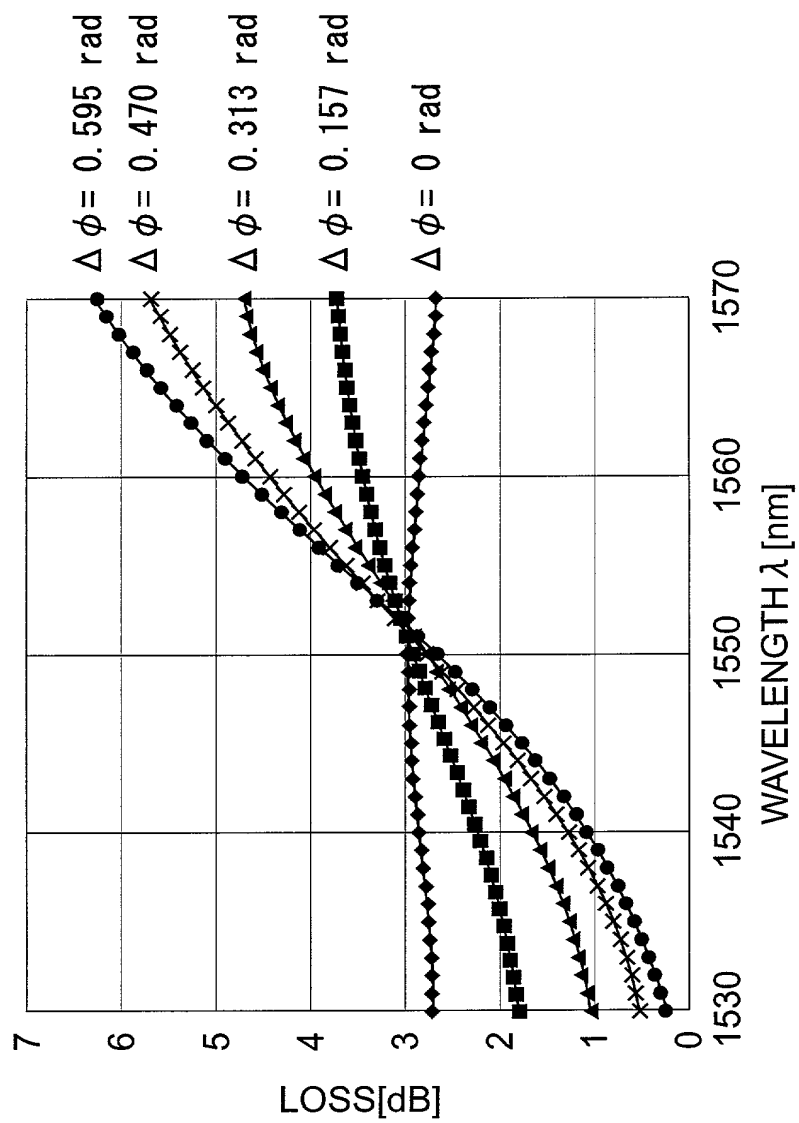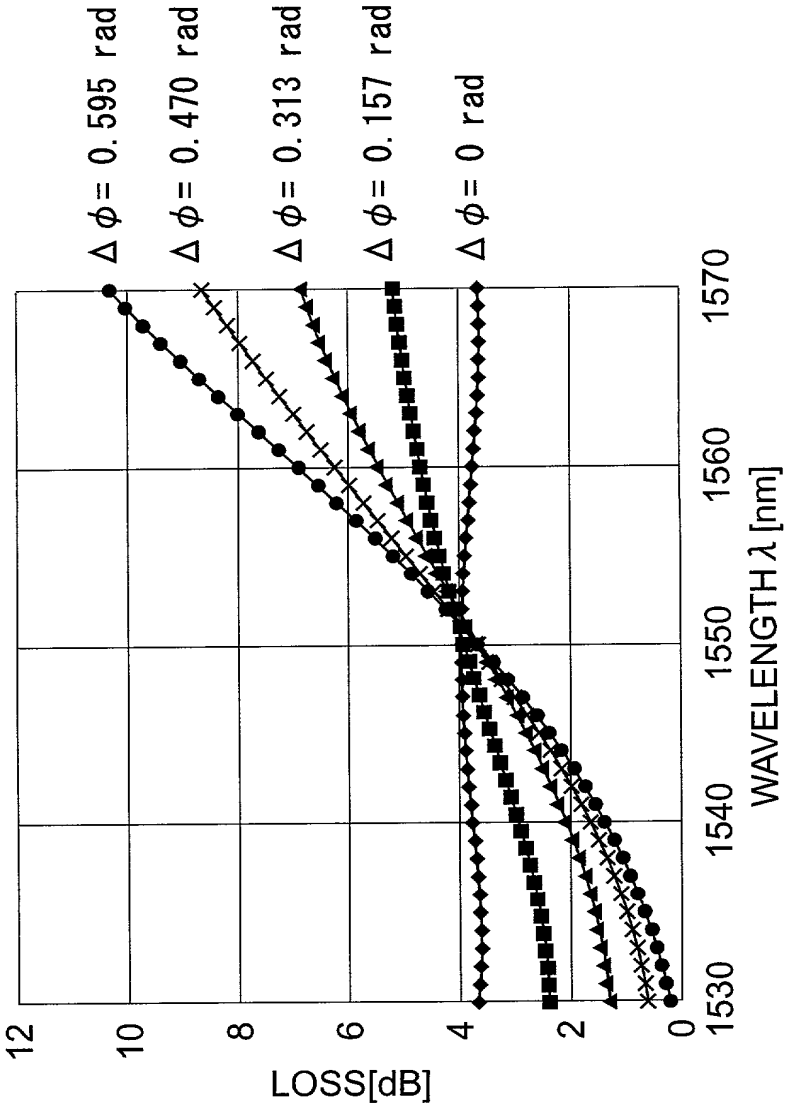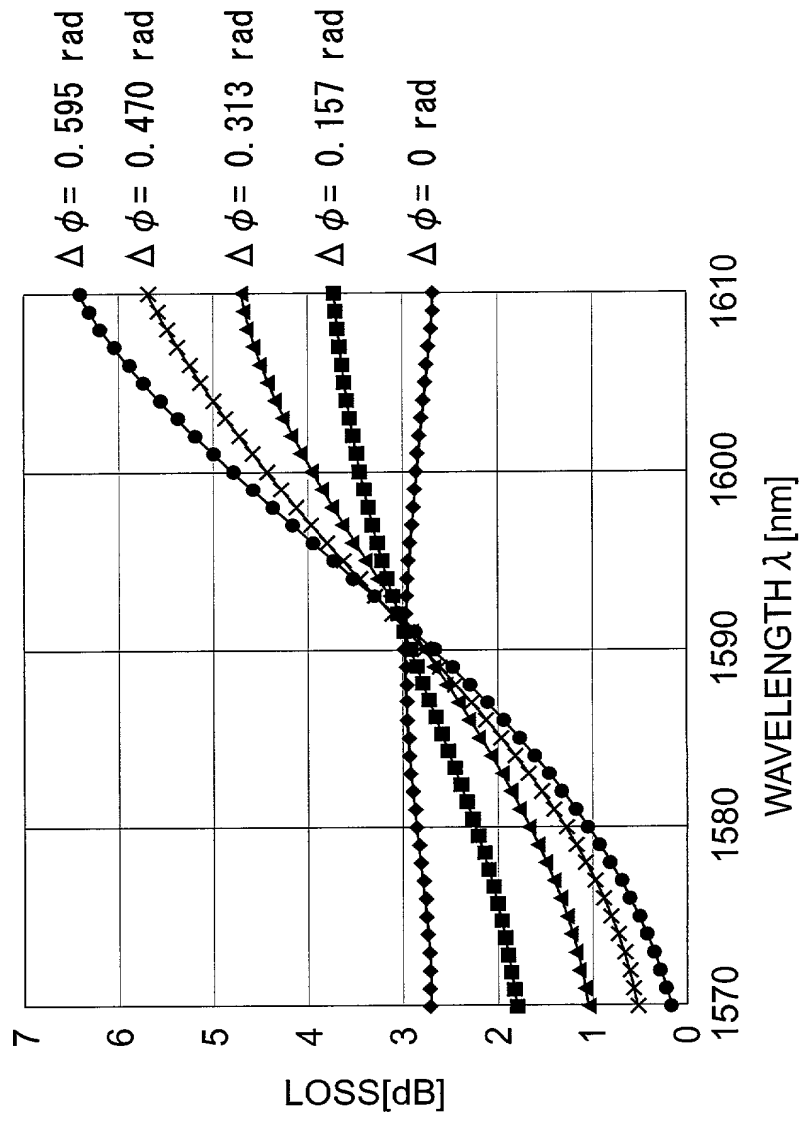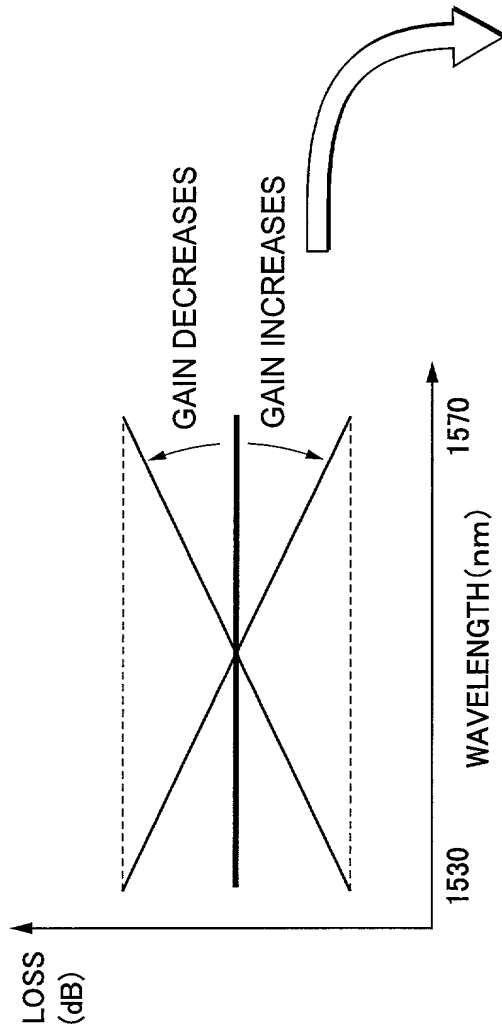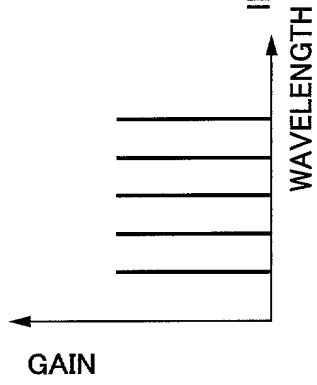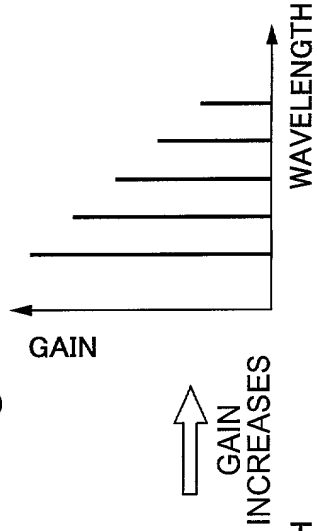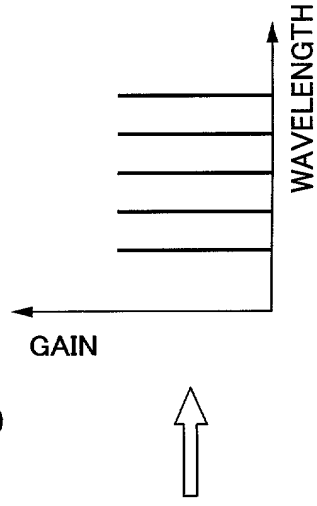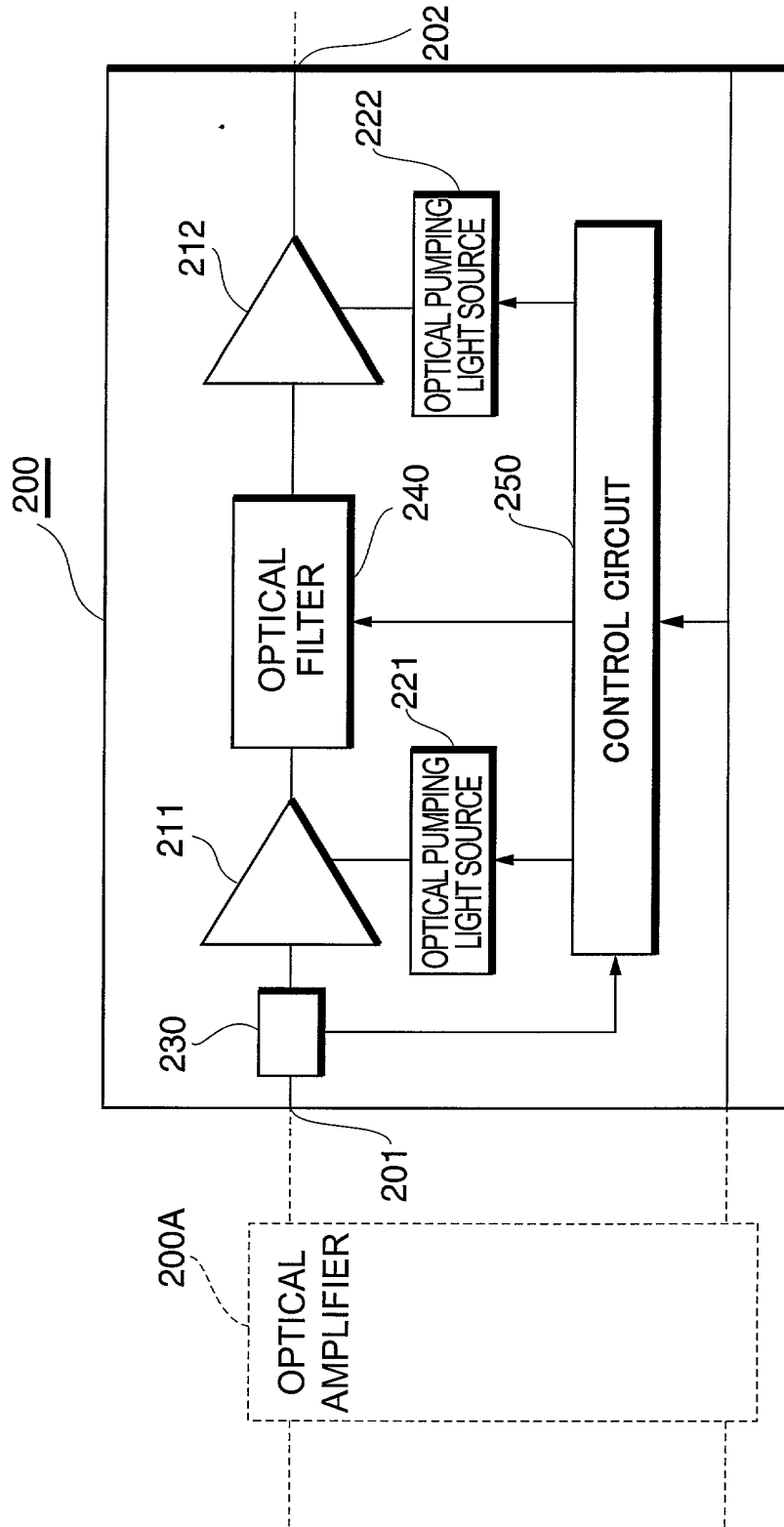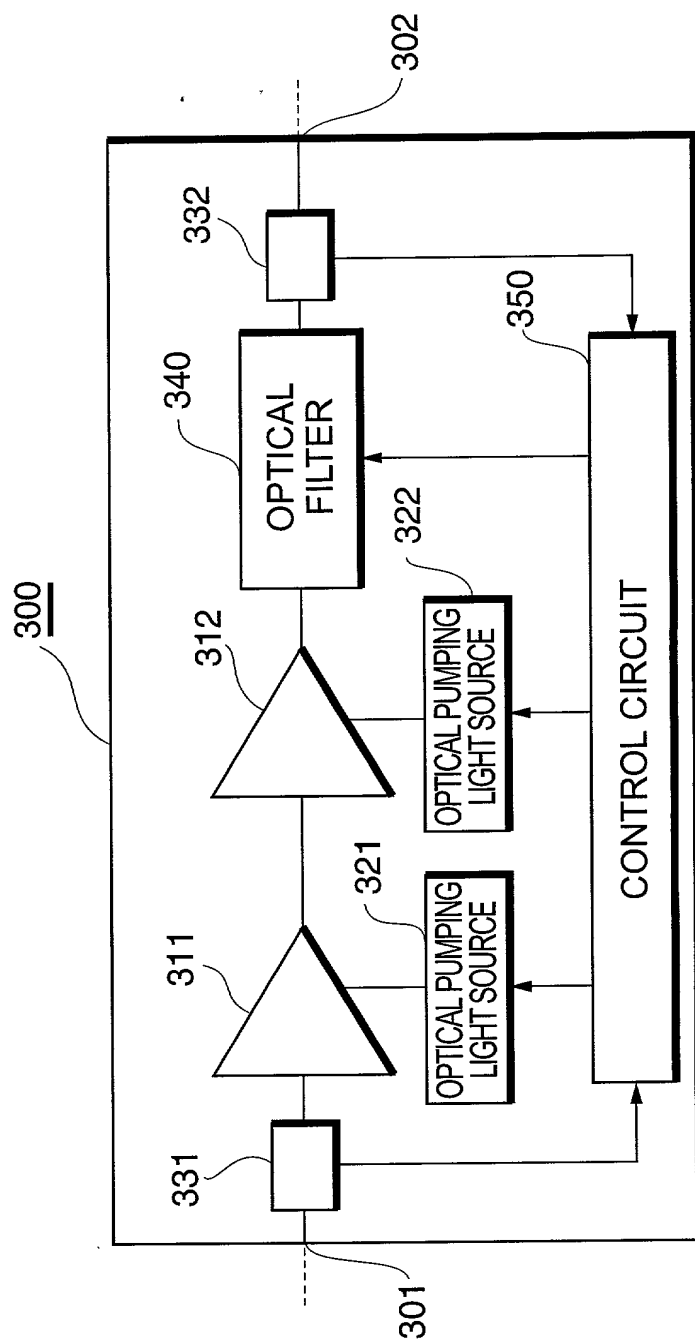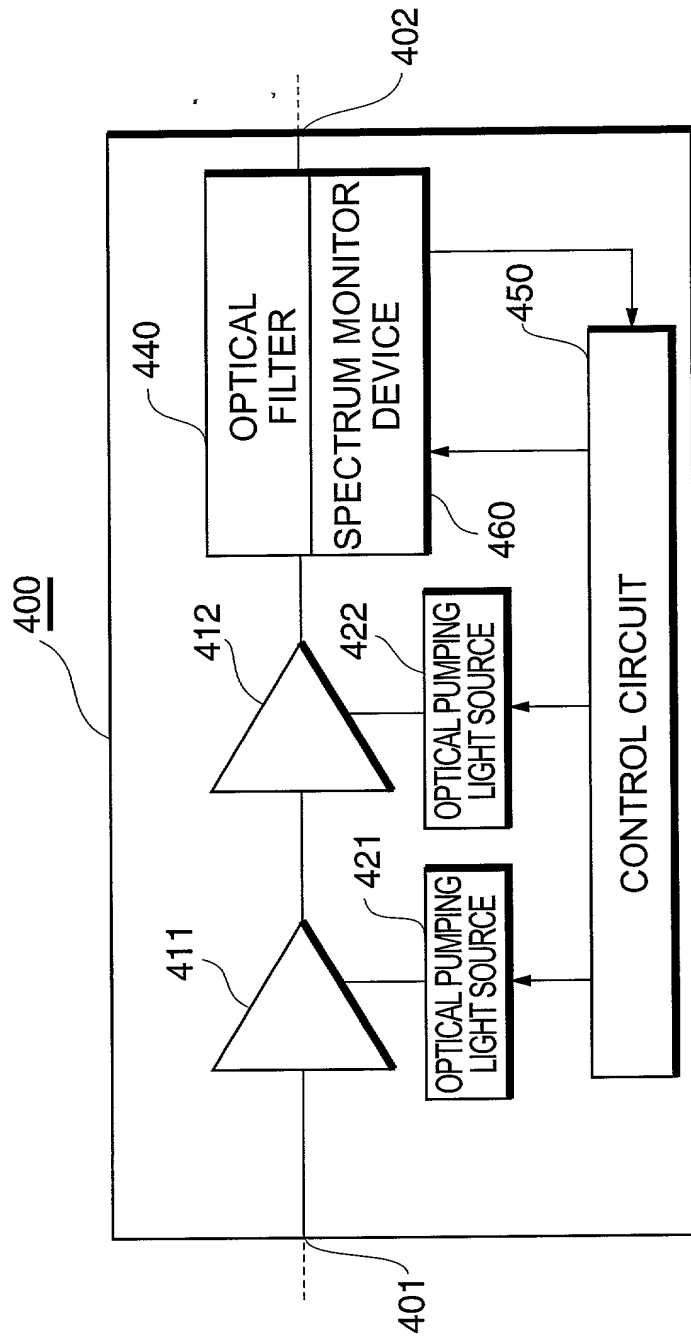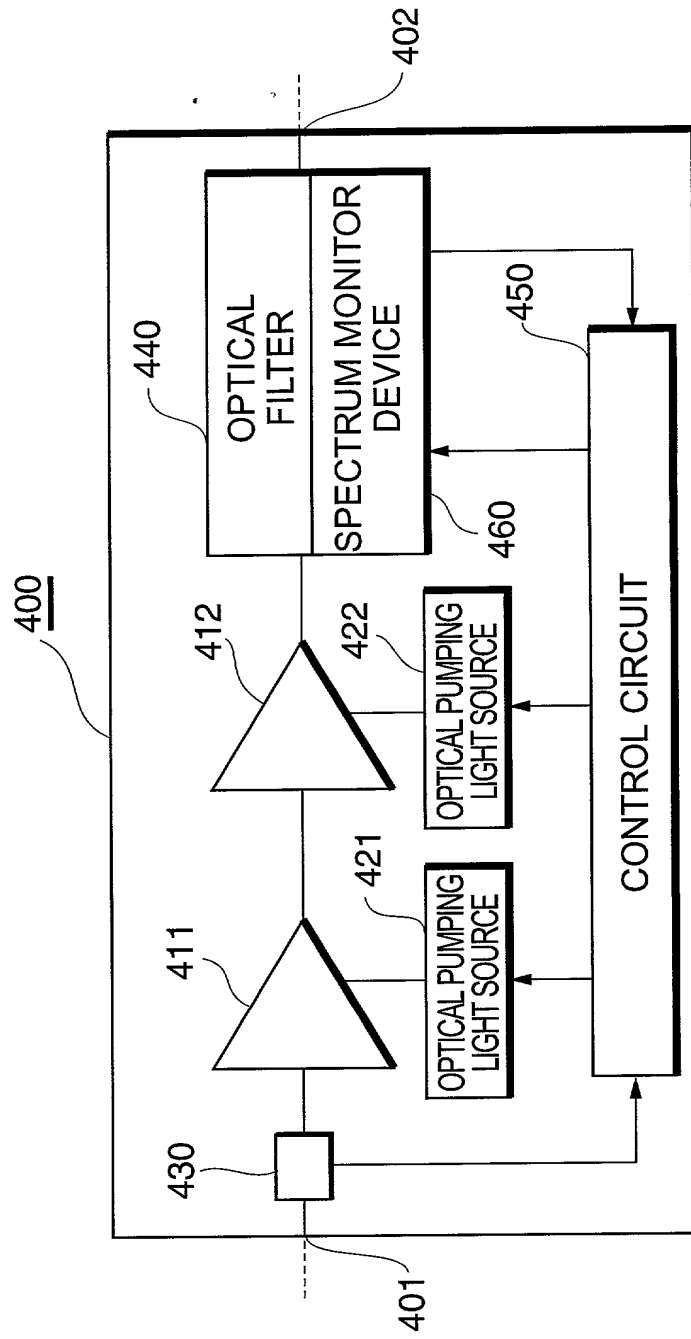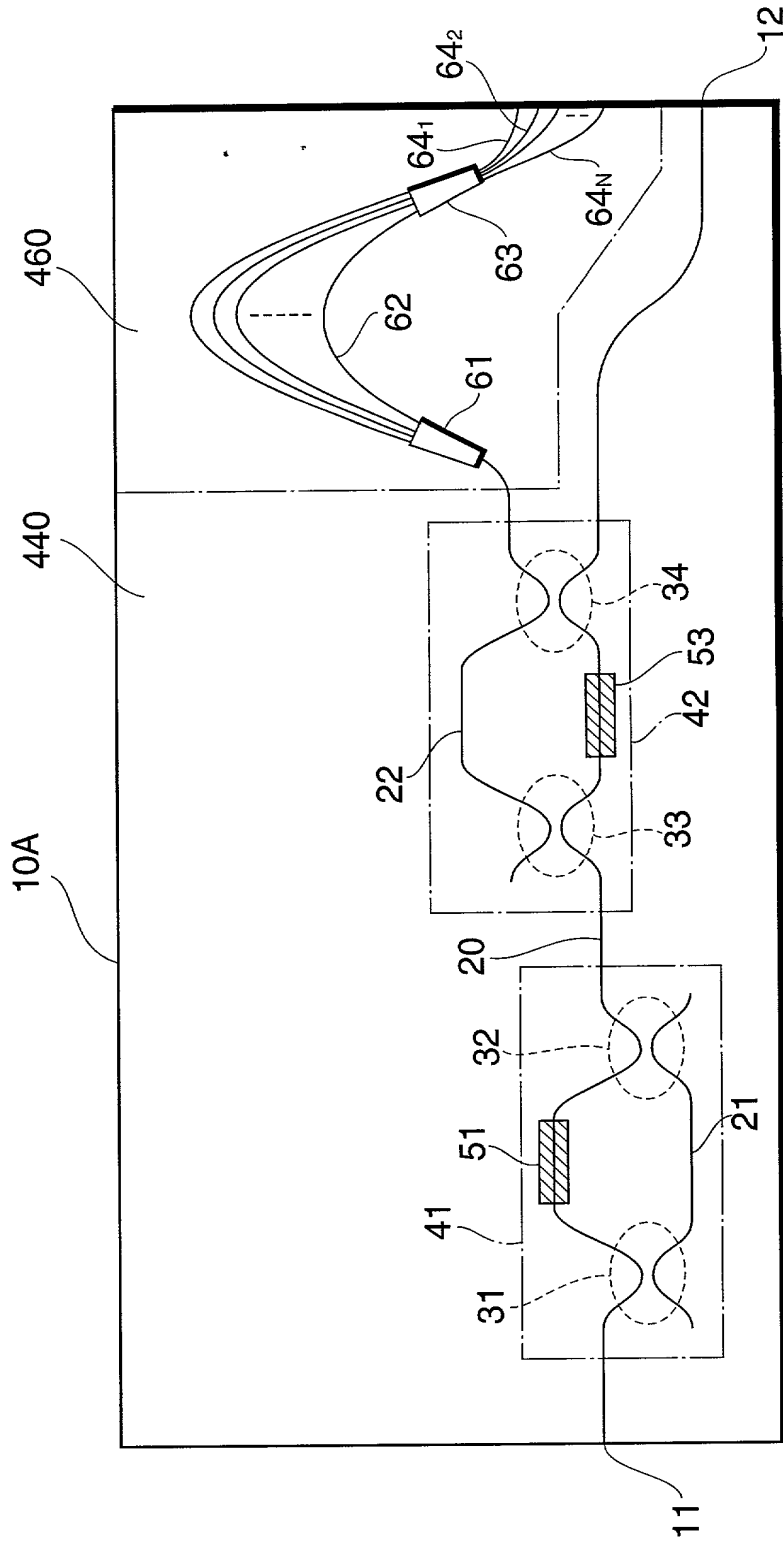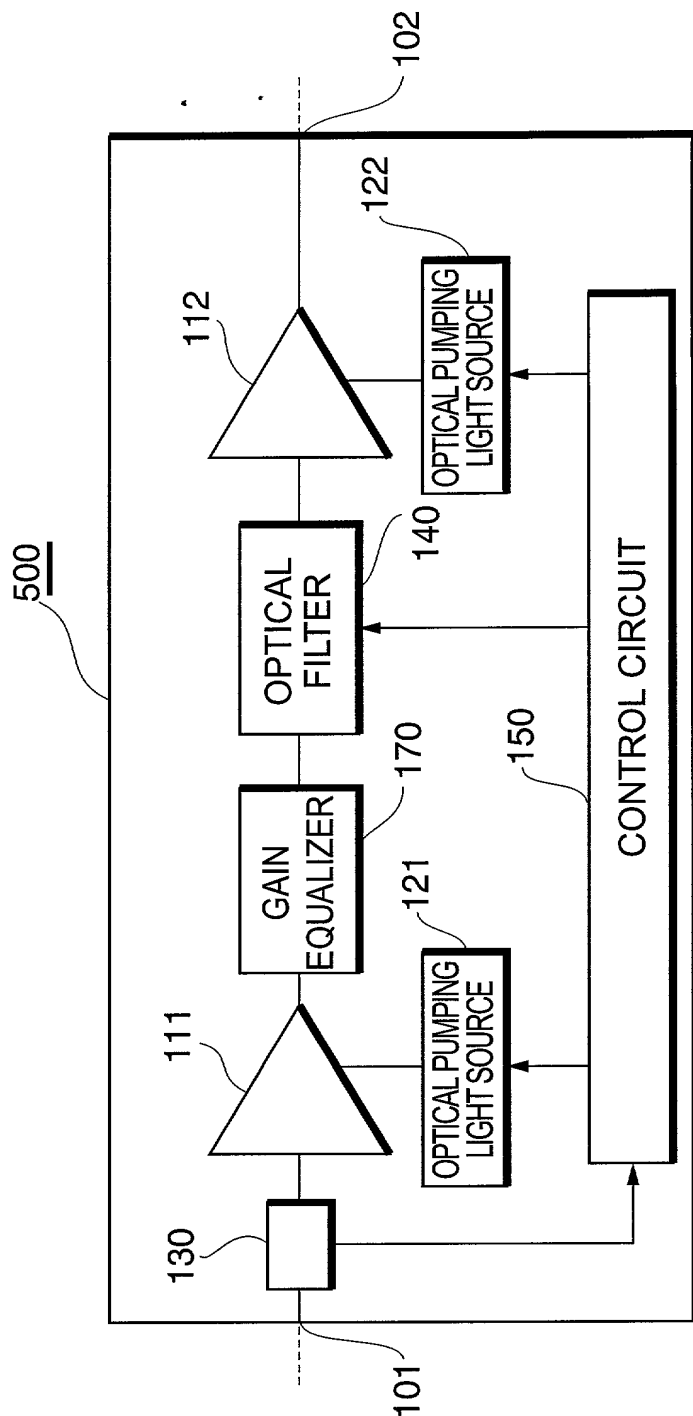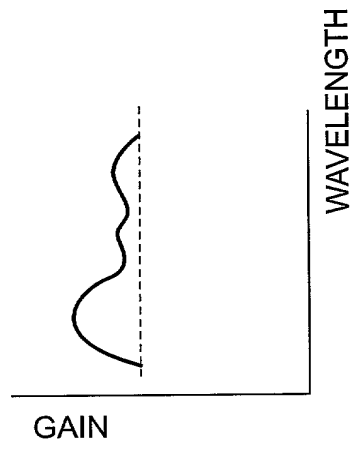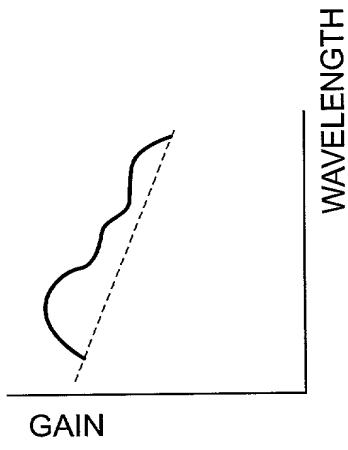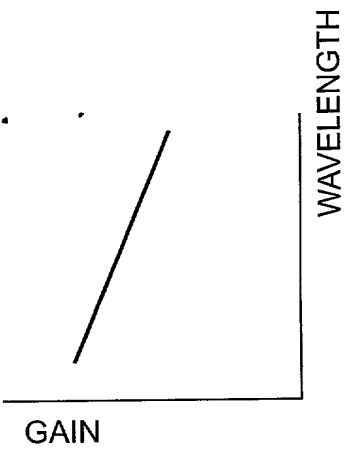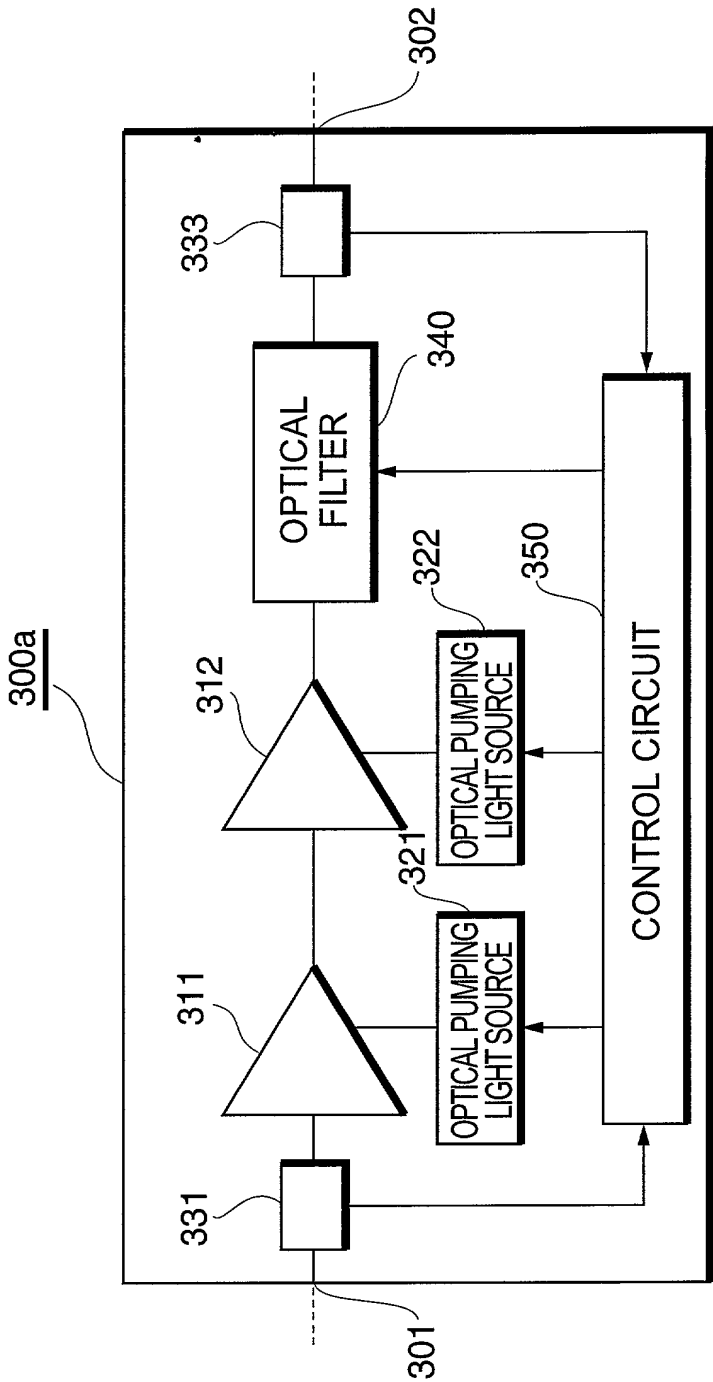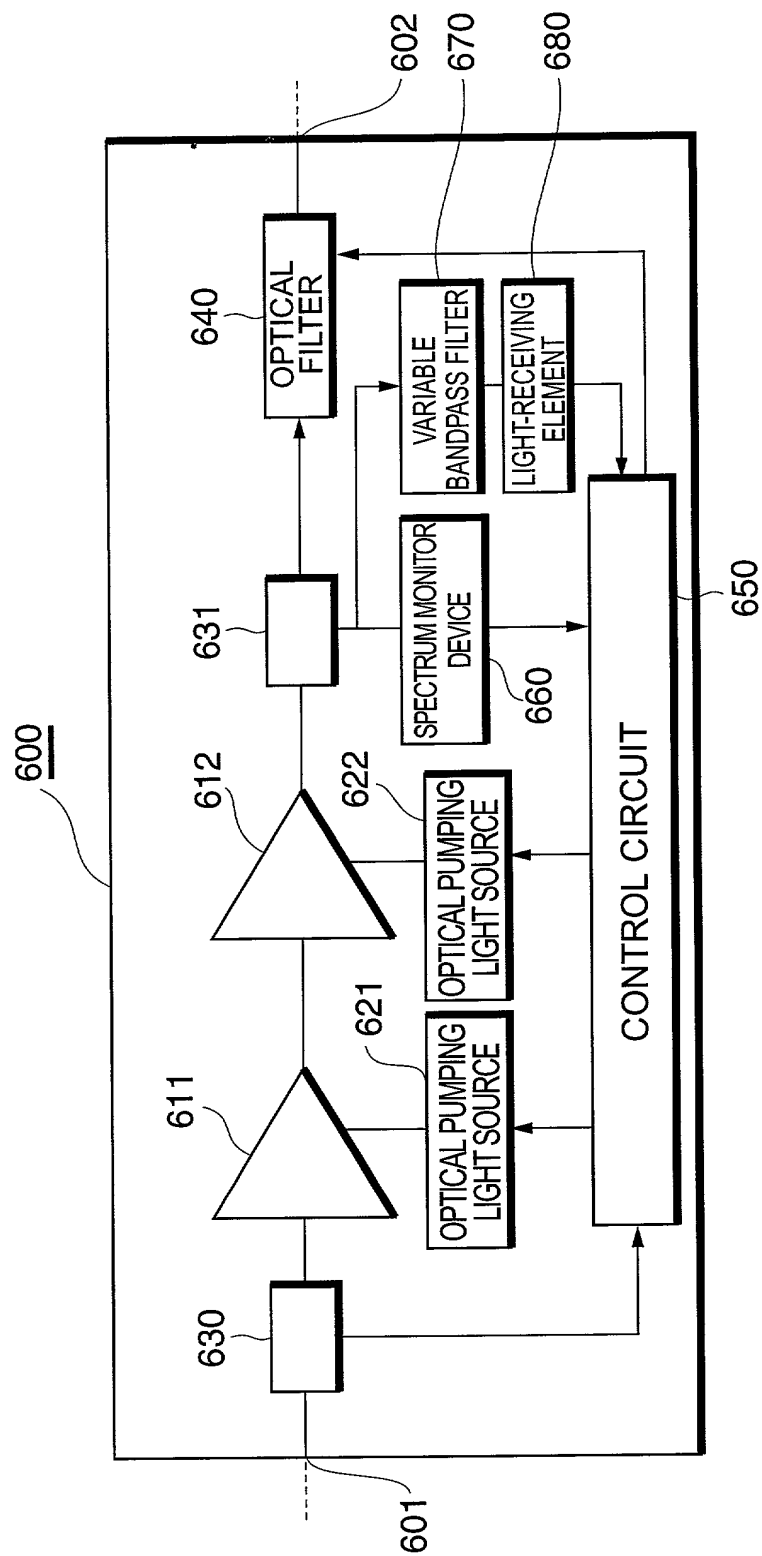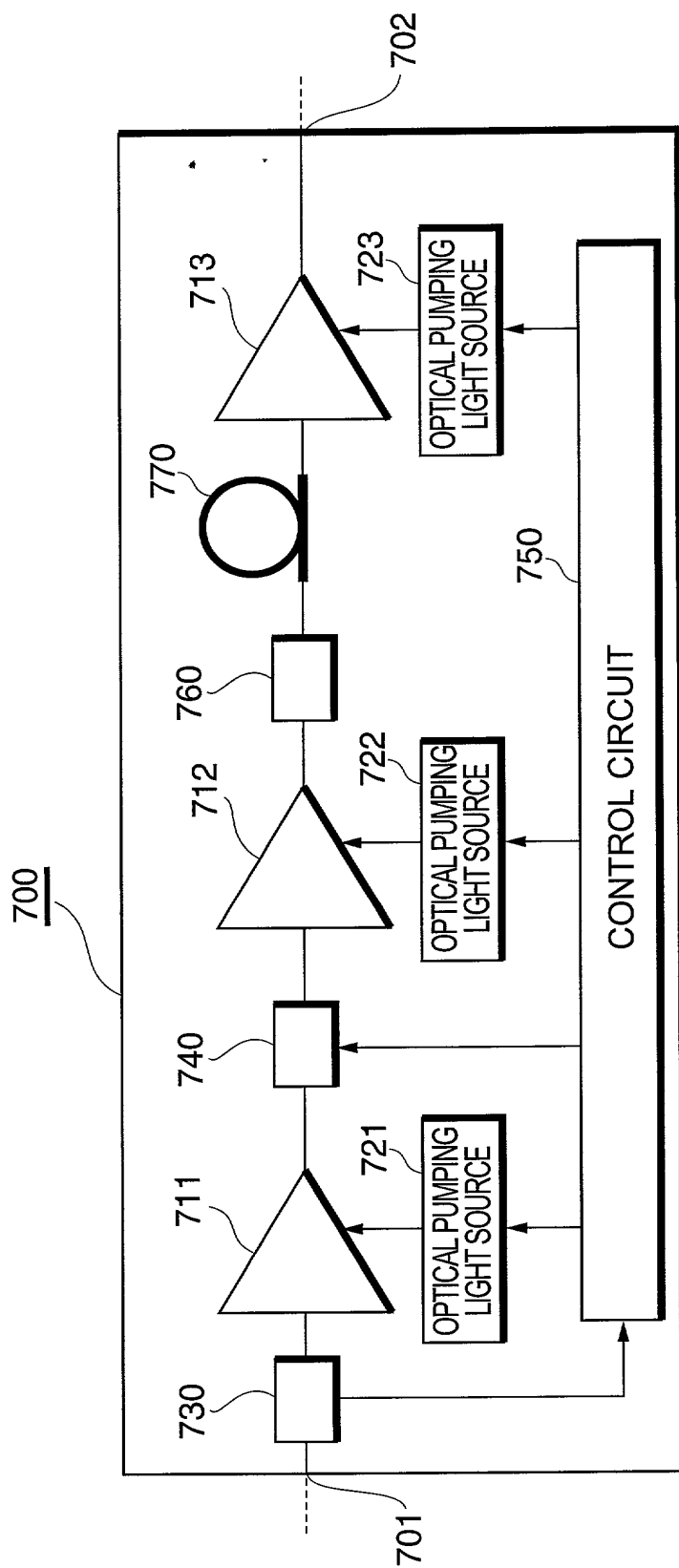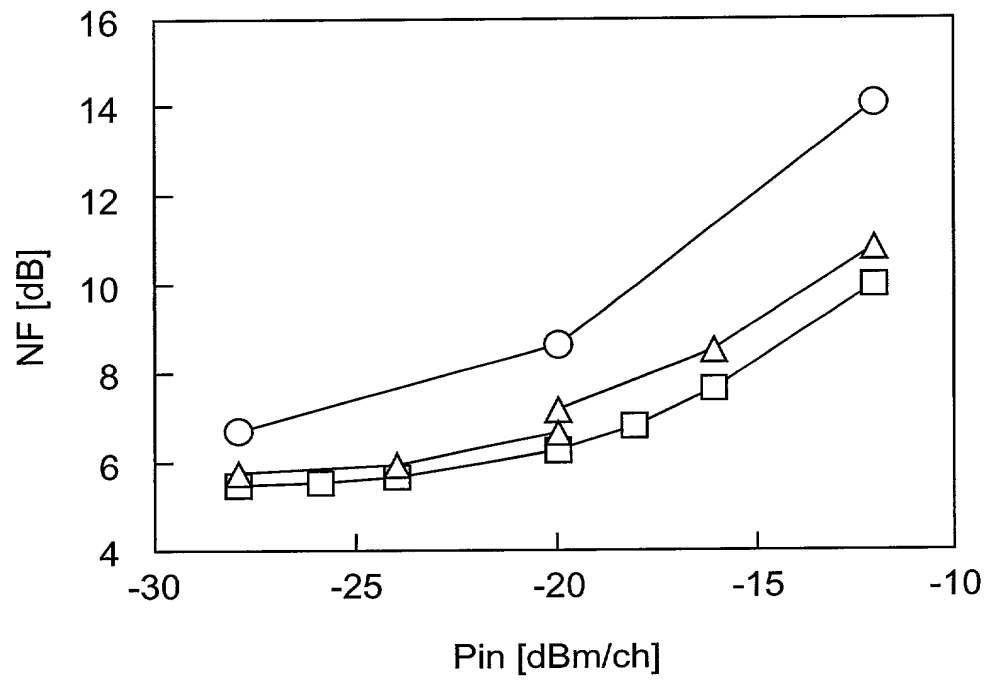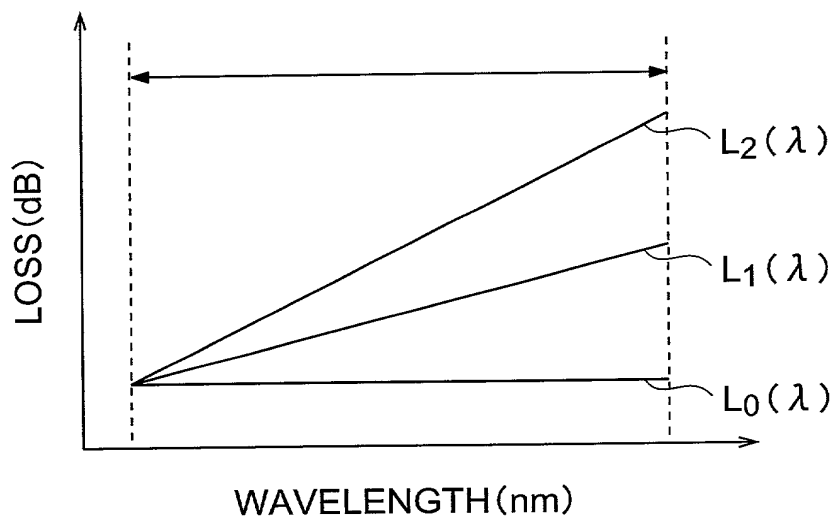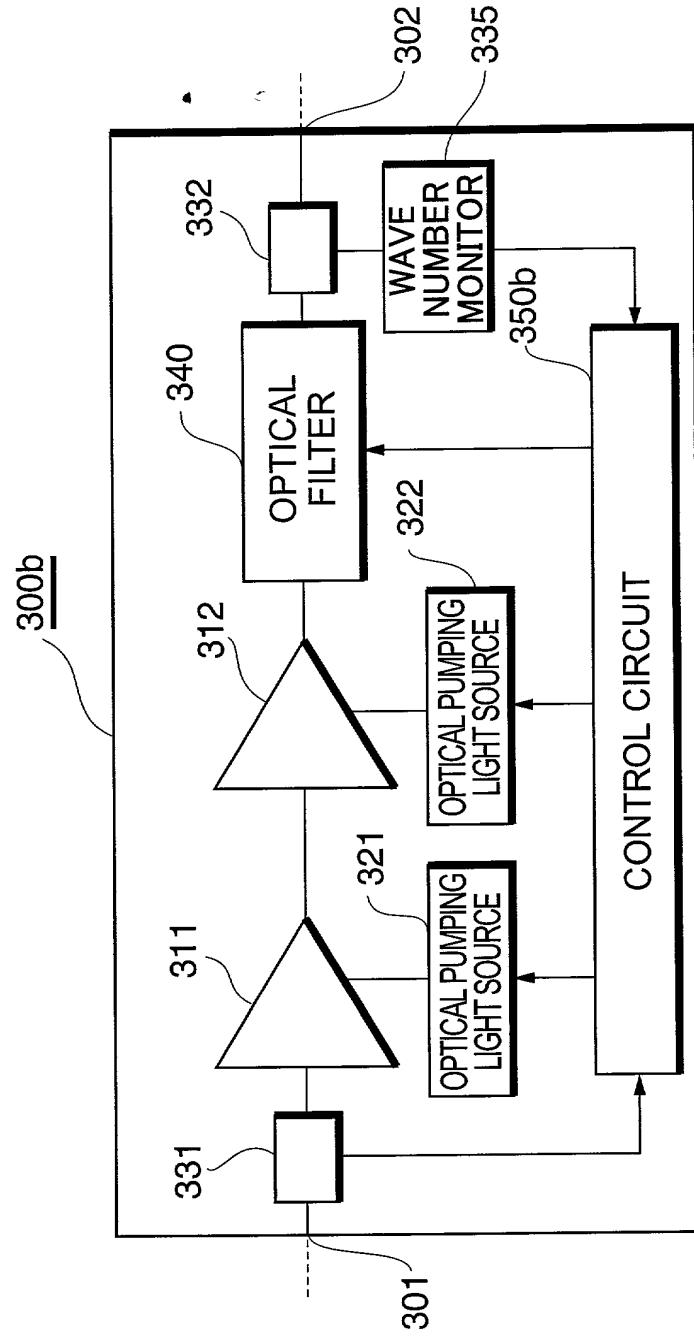
Combined Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

This declaration is of the following type

[ ] original   [ ] supplemental

[ ] national stage of PCT
[ ] divisional   [ ] continuation   [X] continuation-in-part

My residence, post office address and citizenship are as stated next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled
OPTICAL AMPLIFIRE AND OPTICAL AMPLIFICATION METHOD

the specification of which

[X]   is attached hereto.

[ ]   was filed on _____
         as United States Application Serial Number _____ and,
         was amended on _____ (if applicable).

[ ]   was filed on _____
         as PCT International Application Number _____ and,
         was amended under PCT Article 19 on _____ (if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority under Title 35, United States Code, Section 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

PRIOR FOREIGN APPLICATIONS, BENEFIT CLAIMED UNDER 35 USC §119(a)

Application Number	Country	Date of Filing (Day/Month/Year)	Priority Claimed Under 35 USC 119
P1999-196251	Japan	09 / July / 1999	[X] Yes [ ] No
P1999-212190	Japan	27 / July / 1999	[X] Yes [ ] No
			[ ] Yes [ ] No

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.

PRIOR U.S. PROVISIONAL APPLICATIONS, BENEFIT CLAIMED UNDER 35 USC §119(e)

(Application No.)	(Filing Date)	(Application No.)	(Filing Date)
(Application No.)	(Filing Date)	(Application No.)	(Filing Date)

I hereby claim the benefit of Title 35, United States Code Section 120 of any United States application(s), or 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS
DESIGNATING THE U.S., BENEFIT CLAIMED UNDER 35 USC §120

PCT/JP00/01660	March 17, 2000	Pending
(Application No.)	(Filing Date)	(Status: Patented, Pending, Abandoned)
(Application No.)	(Filing Date)	(Status: Patented, Pending, Abandoned)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the registered practitioners of MCDERMOTT, WILL & EMERY included in the Customer Number provided below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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